ProVQ™

DIESEL ENGINE TECHNOLOGY

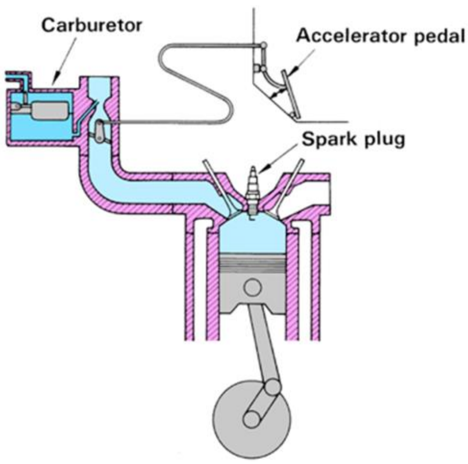
PHASE THREE

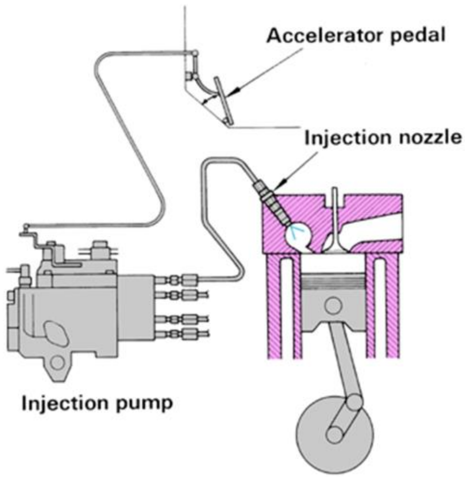
Contents

- ***Diesel fuel system overview***
- ***Diesel fuel***
- ***Diesel fuel system layout***
- ***Diesel pumps***
- ***Rotary pump***
- ***Inline pump***
- ***Common rail high pressure pump***
- ***Injector types***
- ***Injection timing***
- ***Cold start devices***
- ***Emissions***
- ***EGR operation/feedback***
- ***Turbo chargers***
- ***Diesel engine management***
- ***Petrol/Diesel engine mechanical diagnosis***

Diesel Fuel Systems Overview

It is a much-argued case as to who developed the first compression ignition engine. But most of the groundbreaking developments can be attributed to Dr Rudolf Diesel, who in 1892 had successfully developed an engine that relied on heat generated by the compression of air to ignite fuel. Many authorities also feel that some credit is due to Herbert Ackroyd-Stuart, a British engineer who by 1892 had developed and produced for commercial use, an engine possessing all the fundamental features of the modern diesel unit. Ackroyd-Stuart's engine utilised the induction and compression of air, and the timed injection of a liquid fuel by means of a pump.





The only similarity between the fuel system on a compression ignition system and that of a traditional spark ignition system is that fuel is taken from a storage tank at the rear of the vehicle and pumped to a fuel distribution system on the engine through a filter.

However, whereas a spark generated by an ignition coil is used to ignite petrol in a spark ignition engine, diesel engines rely on fuel igniting spontaneously as it enters the combustion chamber and mixes with highly compressed air. This process can only be achieved using accurately machined components designed specifically to deliver fuel in precise quantities, at the right time. The fuel delivered must be free of contaminants such as dirt deposits, water and air to ensure that components remain in good condition.

The fuel is initially delivered at low pressure to an injection pump capable of increasing the fuel pressure to very high levels, for delivery to the combustion chamber via devices called injectors. Aside from the fuel system, the major components i.e. crankshaft, pistons etc, of the engine itself are very similar to those of a petrol engine.

Compression Ignition (CI) or Diesel engines as they are more commonly known, have some disadvantages when compared to similar size/output petrol versions:

- diesel engines are usually heavier than equivalent petrol versions because of the higher stresses involved in the combustion process
- the noise and vibration levels of diesel engines tends to be higher for the same reasons
- diesel engines often require more frequent maintenance and servicing due to the need to maintain the precision of the high-pressure fuel injection system
- fuel is required to be filtered more efficiently
- high compression pressures demand better starter systems, e.g. bigger batteries, cables and starter motors
- a system of pre-heating is normally required to ensure good starting in cold conditions
- diesels are generally prone to smokier exhaust emissions

Naturally the above differences can add to the manufacturing cost, which is usually reflected in a higher initial vehicle purchase price. Some of these higher initial costs and other disadvantages listed above may be offset by the following advantages of diesel engines:

- the fuel economy of diesel engines generally better than that of petrol versions due to their higher thermal efficiency
- no ignition system is required. The absence of high voltage wiring and components avoids the risk of water ingress affecting reliability and reduces servicing costs/time
- the low engine speed pulling power (torque) is high in diesels. This makes them particularly suitable for use in load-carrying vehicles

Diesel Fuel

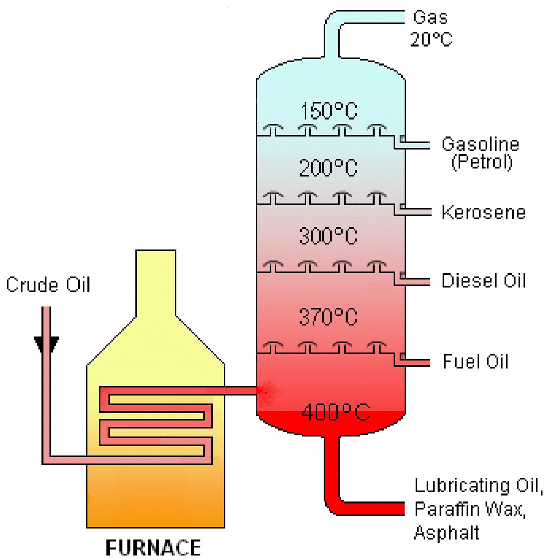
As with any combustible substance, diesel fuel is regulated under the Control of Substances Hazardous to Health Regulations 1994 (COSHH). Safety measures should be stringently observed when a risk of exposure to diesel fuel or fumes is present. In addition, fuel injection pumps deliver fuel at pressures above 250bar and fuel at these pressures can penetrate human skin with possibly fatal results. Skin contact with diesel fuel could also result in dermatitis and other skin diseases. When working on the fuel system when contact with diesel fuel cannot be avoided, using eye protection, barrier cream and gloves can significantly reduce the risks.

Diesel fumes and exhaust emissions have the potential to cause a range of health problems including coughing, chest pain and breathlessness. There is some evidence that prolonged exposure to them can increase the risk of cancer. Diesel fumes are products of the combustion process and evaporation containing a combination of gases, vapours and particles including:

- Carbon monoxide CO
- Hydrocarbons HC
- Oxygen O2
- Carbon dioxide CO2
- Oxides of nitrogen NOX
- Carbon (soot) C

Boiling point range

Hydrocarbon (HC) based fuels are normally made up of a mixture of different basic hydrocarbon elements. Each hydrocarbon element has a different boiling point and in diesel fuels these mixtures usually result in the boiling point ranging from around 180ºC to 380ºC.

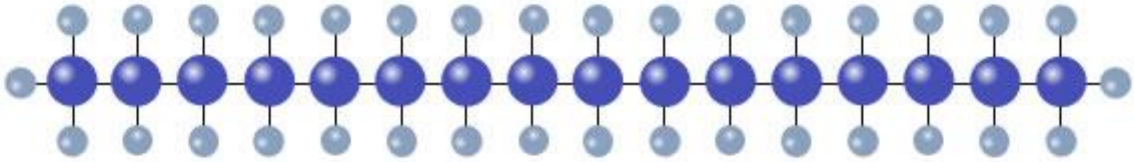


Adjusting the proportion of the hydrocarbons in the fuel to reduce the boiling point improves the fuel's operating properties in cold conditions but may reduce its lubricating qualities, risking increased wear of the fuel injection system. The ignition quality of the fuel is also reduced (see "Cetane number")

Conversely, increasing the boiling point of the fuel improves the lubrication quality and ignition quality but usually results in higher soot emissions and carbon contamination of the engine components.

Diesel is made from crude oil and is refined to produce the fuel we know as diesel. Diesel is chemically known as Cetane and consists of a mix of hydrogen and carbon.

Cetane (diesel)
C16 H34
Cetane number



typical diesel chemical composition
cetane, or n-hexadecane is typical of diesel fuel - $C_{16}H_{34}$

The Cetane number is a measure of the ability of a diesel fuel to burn spontaneously and immediately when injected into the hot, compressed air in the combustion chamber (ignition quality). National and international standards apply to the Cetane rating, which is determined by testing in a standard test engine. For clean, smooth engine operation a Cetane number above 50 is necessary for fuel supplied in Europe. The Cetane number may be as low as 45 when the fuel is used in arctic conditions as the processes used to make the fuel flow in cold conditions usually reduce its ignition quality.

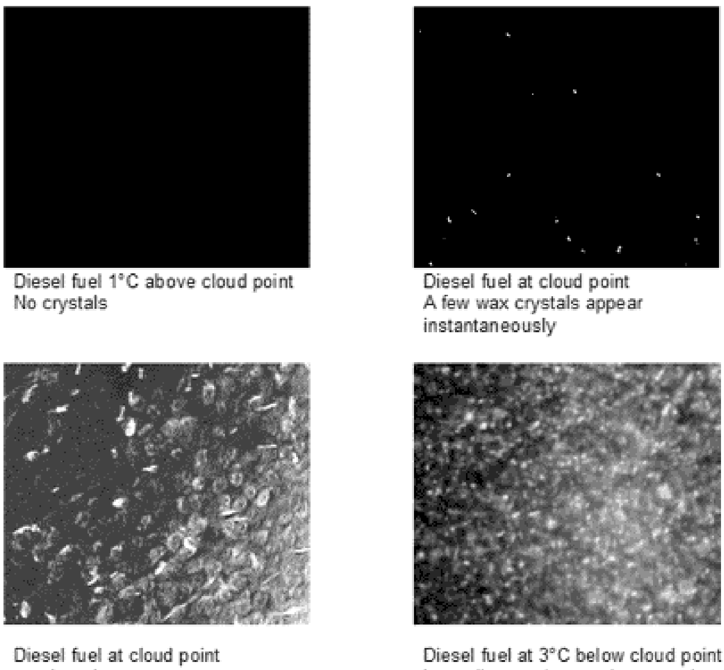
Flash point

The flash point is the temperature at which vapour emitted to the atmosphere from a liquid fuel can be ignited by a spark. This has implications for transport and storage of diesel fuels and they must not have a flash point below 55ºC. It used to be commonplace for operators to add petrol to diesel fuel in cold conditions in order to improve the cold starting of some engines. Adding just 3% petrol is sufficient to reduce the flash point to around room temperature, making storage and handling of the fuel extremely hazardous. Fortunately, modern fuels conforming to legal standards contain chemicals which make adding petrol to diesel fuel unnecessary.

Cold flow properties and filtration

Diesel fuel contains paraffin, which at low temperatures can crystallise and result in blockages in the vehicle's fuel filtration system. This paraffin crystal precipitation is sometimes known as "Waxing". Under some conditions waxing can occur at ambient temperatures as low as 0ºC, making the addition of cold flow-improving chemicals necessary even in

Microscope pictures of a typical diesel fuel



Diesel fuel 1°C above cloud point
No crystals

Diesel fuel at cloud point
A few wax crystals appear instantaneously

Diesel fuel at cloud point
one hour later
More crystals formed

Diesel fuel at 3°C below cloud point
Immediate and extensive crystal formation

temperate, European climates.

These additives are normally added to the fuel at the refinery in the country of use and do not actually prevent waxing but they do limit the size of the paraffin crystals, allowing them to pass through the filtration system without causing blockages.

Other additives

A number of additives are necessary to improve the performance of diesel fuels in specific conditions. These are added as packages depending on the expected operating conditions in the country of use. The total concentration of these packages rarely exceeds 0.1% of the fuel and has little effect on the fuel's physical characteristics, e.g. density, viscosity and boiling point range.

Detergents – used to help keep the intake system and prevent deposits of carbon on the injectors and in the combustion chamber.

Corrosion inhibitors – help prevent corrosion of metallic components caused by moisture entering the system.

Anti-foaming agents – used to reduce the tendency of diesel fuel to froth or foam when agitated, e.g. during re-fuelling.

Environmental issues

Various countries have promoted the use of more environmentally friendly diesel fuel. In these fuels the aromatics and sulphur content is reduced and the boiling point is lowered. However, the use of special additives is required to prevent wear and other damage to diesel fuel systems caused by some or all of these changes.

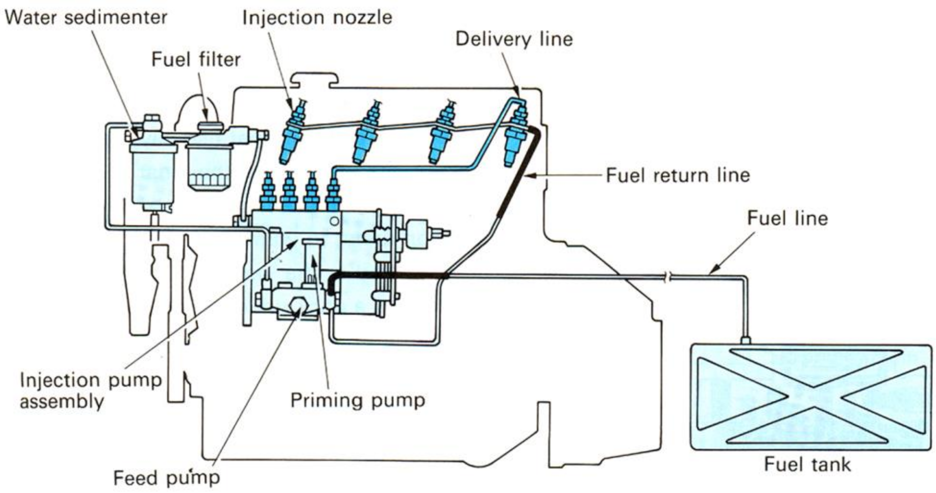
Diesel fuel system layout

A typical fuel injection system is manufactured to very fine tolerances and its components must endure the extreme operating pressure developed during the injection process and combustion. The delivery of clean filtered fuel is critical to the operation of the fuel injection pump and therefore the fuel is filtered prior to the filling of the fuel tank, at the filter assembly and at the inlet side of the delivery pump.

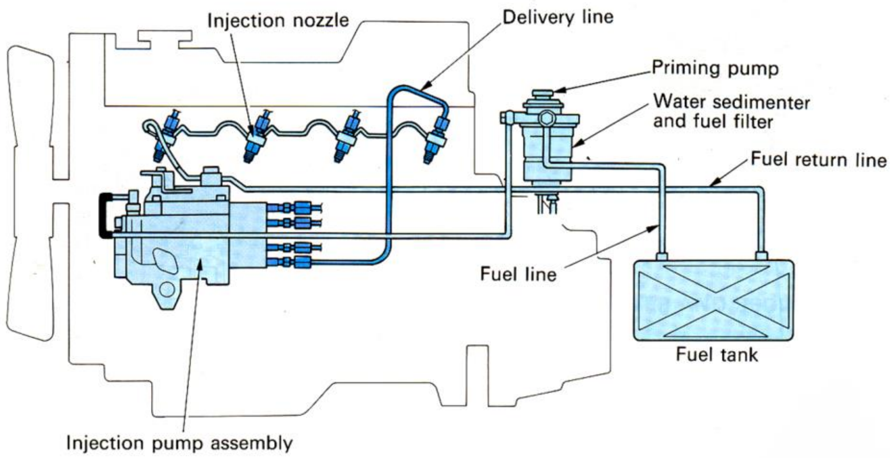
Water in the fuel system leads to corrosion and poor running. A water sedimenter is incorporated in to the filtering system to ensure that any water entering through condensation or the refuelling process is removed before it reaches the injection pump.

A feed pump is used to ensure a constant supply of fuel to the injection pump; the pump often incorporates a hand-priming device used to bleed air out of the fuel lines following component changes or in the event of the vehicle running out of fuel. The fuel injection pump assembly is responsible for the fuel delivery to the injectors.

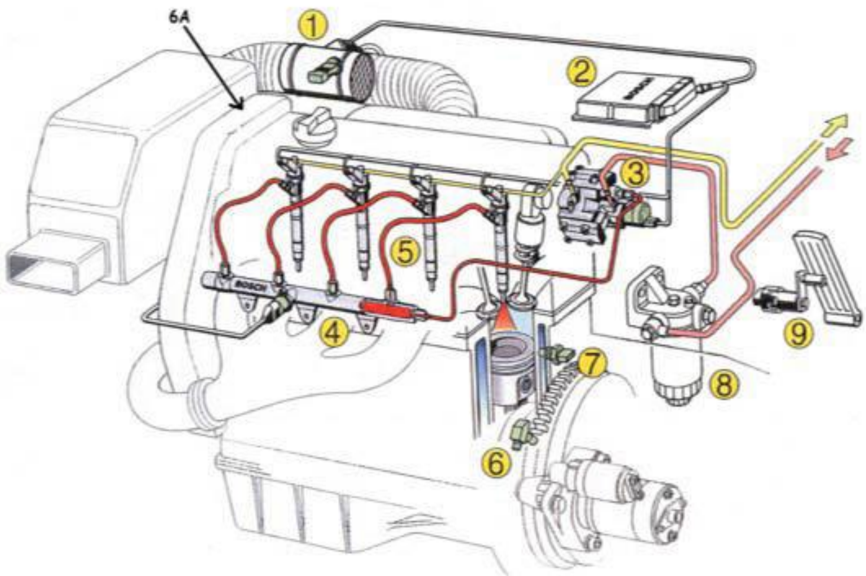
Inline pump



Distributor type pump



Common rail

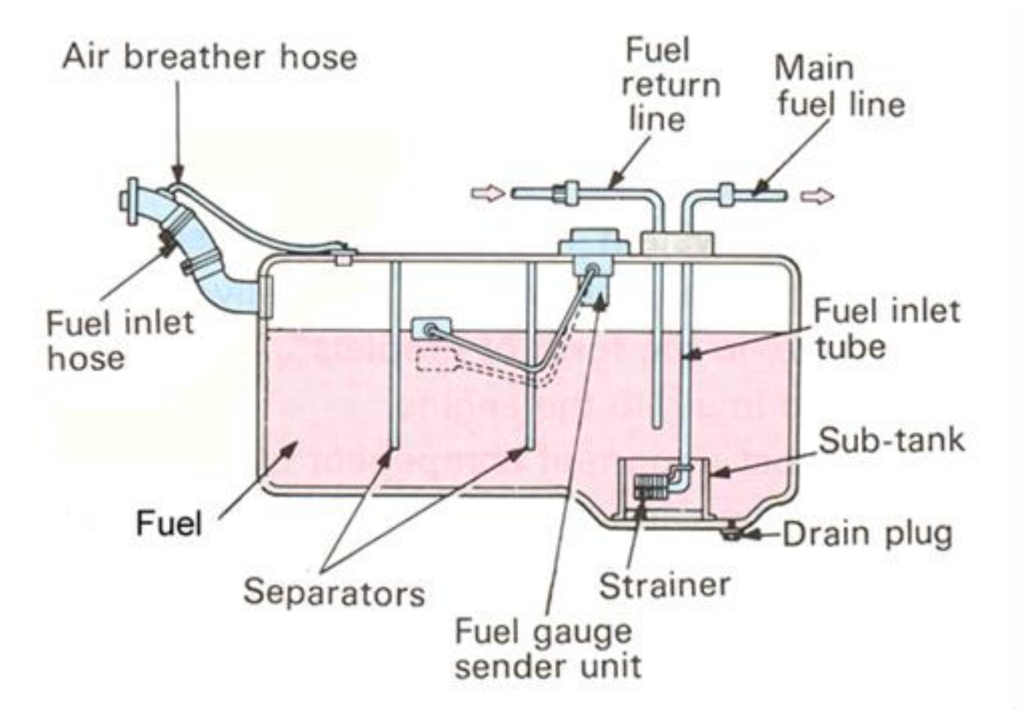


Fuel tanks

The fuel tank is designed to contain fuel safely and conveniently. Modern fuel tanks may be constructed from sheet steel or increasingly of moulded plastic. Their positioning and size depends on a number of considerations:

- where they can be best protected from damage in accidents
- where they can be easily filled – this may involve pipework connecting the tank to the filler opening
- how much room is available in the vehicle design
- how the positioning may affect the vehicle handling when differing quantities are carried. Designers normally attempt to place the tanks as low and as close to the centre of the vehicle as possible
- the engine size and its anticipated fuel consumption – especially in commercial vehicles where long journeys may be undertaken regularly and too many stops may adversly affect journey times and costs. Similar considerations affect cars as well, where too many stops for fuel may be inconvenient

In early vehicles, fuel tanks were positioned as high as possible between the engine bulkhead and the base of the windscreen to allow the fuel to be fed by gravity to the engine. Mainly due to the above conditions and the improvement of fuel pumps this system is now rare. Most car manufacturers have moved to plastic fuel tanks which can be easily shaped to fit exactly within the vehicle floor design near the centre of the vehicle. Fuel tanks are rarely a simple box – they contain several components.



Separators

Separators or baffle plates are built in to a fuel tank to provide rigidity and to prevent the fuel splashing during vehicle movement. If diesel fuel is agitated excessively air bubbles can be formed which may affect the smooth running of the engine. Some separators can prevent fuel from surging backwards and forwards too quickly when driving up and down inclines, reducing the risk of fuel starvation or air being drawn into the system, especially when the fuel level in the tank is low.

Fuel inlet assembly and breather system

A fuel filler neck, which may be mounted to the vehicle body, mainly in the case of cars and light vans is connected to the fuel tank by a fuel Inlet hose. The filler neck provides a mounting for the filler cap which seals the tank after re-filling. The hose allows for possible movement between the body and the tank in order to prevent damage to components caused by vibration. The hose also allows for slight differences in the positioning of the tank and usually makes the fuel tank easier to remove/replace.

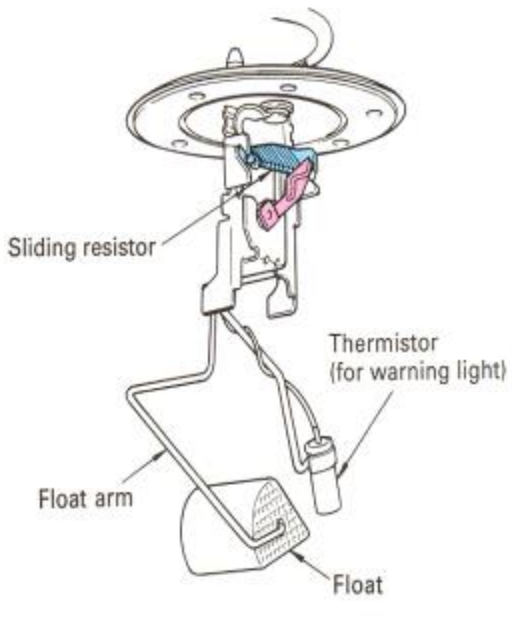
A breather system has three main tasks. Firstly, it allows air to replace fuel used by the running engine. Without this system, the engine may be starved of fuel by vacuum built up in the tank as fuel is pumped out. It is not unknown for tanks to collapse when the breather system fails, particularly on vehicles with especially powerful fuel pumps. The breather also allows air in the tank to be displaced as fuel is delivered to the tank, preventing splashing which can make refuelling difficult. Finally, the breather allows internal pressure to be released. This pressure can be built up when vehicle movement agitates the fuel or when fuel returns to the tank from the engine.

Fuel Strainer

Many fuel tanks contain a fuel strainer, and this is the first point at which fuel is filtered. Most are made of metal gauze plates and are designed to prevent ingress of larger dirt/paint particles into the fuel pipes as the fuel is drawn from the tank by the pump. Fuel strainers may form part of a removable fuel feed pick-up pipe and sometimes they are combined with the fuel gauge assembly.

Fuel strainers in small vehicles, which usually receive fuel from “clean” forecourt pump sources, are not normally replaceable unless they are combined with other assemblies as above. Larger vehicles, which may receive fuel from less reliable sources, often have replaceable strainer assemblies bolted into the tan*Fuel Gauges*

Some commercial and agricultural vehicles still provide the driver with a dipstick or sight tube to measure the fuel level. More commonly, an electrical fuel gauge provides the driver with information on the amount of fuel in the tank. This may be presented to the driver as the proportion of fuel left or used, or in actual quantities e.g. litres/gallons. The gauge itself receives information from a sender unit mounted in the fuel tank.



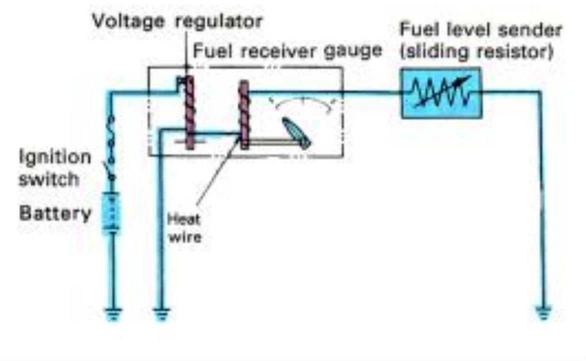
FUEL LEVEL SENDER

A number of different systems are used, largely dependent on the application. The most common being the bi-metal resistance type and the cross-coil type which are described below.

Bi-metal-resistance type

This method of gauging fuel levels uses a bimetal element in the receiver gauge combined and a float type variable resistor in the sender unit located in the fuel tank. The float rises and falls with the fuel level. The float arm is connected to a sliding resistor. As the float moves up or down the position of the contact on the resistor will move with it, thus, varying the resistance. A voltage regulator is fitted into the circuit to compensate for any fluctuations in supply voltage which may affect the accuracy of the gauge.

When the ignition is turned on, current flows through the voltage regulator and heat wire (bi-metal strip) in the fuel receiver gauge, going on to earth through the sliding, variable resistor on the sender unit located in the fuel tank. The heat generated by the current distorts the bi-metal element varying amounts depending on the resistance of the sender unit. If the fuel tank is full, little resistance will be felt, allowing more current to flow, providing more heat to distort the bi-metal strip and more deflection. When the tank is less full, the resistance of the variable resistor increases and current flow is reduced throughout the circuit. The reduction in current allows the bi-metal strip to cool and the gauge now shows the reduced fuel level.



Low pressure fuel lines

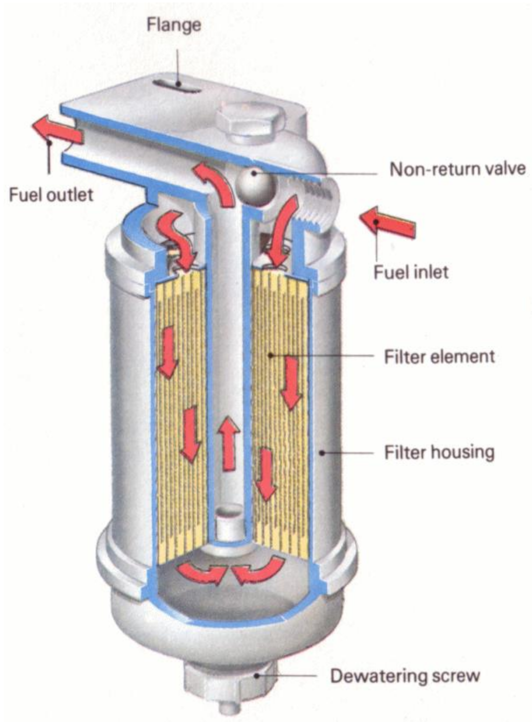
Low pressure fuel lines are used to connect the fuel tank, filters, pumps etc together. Fuel is delivered to the engine through a supply pipe and excess fuel flows back to the tank via a return pipe. These lines may be rigid metal or plastic pipes, or rubber hoses. Metal pipes are usually used where they can be secured to the vehicle floor or chassis and where disconnection/removal is unlikely to be required during routine servicing. Flexible hoses are used where movement is likely, I.e. between the chassis and the flexibly mounted engine to minimize damage caused by vibration or when components such as filters are regularly disconnected during servicing. The size of these fuel lines largely depends on the size of the vehicle and its engine but low pressure fuel lines tend to have an internal diameter of between 6mm and 12mm.

Fuel Filters

The purpose of the fuel filters is to remove dirt, foreign bodies and other impurities from the fuel prior to it entering the injection system. Unfiltered fuel can cause serious damage to sensitive, accurately machined components and rapidly clog injectors. As previously mentioned fuel is filtered at various stages in the supply system and we already know that fuel is often strained as it leaves the fuel tank. It also passes through a fine gauze mesh filter basket at the supply pipe connection to the fuel injection pump.

Main Filter

In addition to the tank strainer and final filter gauze in the injection pump; all diesels incorporate a main (primary) filter, located between the fuel tank and the injection pump. These fuel filters prevent small but potentially damaging particles entering the sensitive components of the diesel injection system and as such are vital parts which need to be replaced at regular intervals. Just by doing the job they were designed to do, that of preventing anything other than clean fuel travelling further along the fuel system towards the engine, they will eventually become clogged.



Main filters usually consist of a pleated roll of specially treated paper capable of trapping particles of dirt larger than about 5 microns (5 millionths of a metre) in diameter. If opened out, the paper in a typical filter would cover an area of approximately half a square metre.

These filters will naturally retain almost any foreign bodies entering the fuel system including particles of dirt, fluff from rags and paint flakes from the inside of tanks and cans. In some cases, when the temperature is very cold, i.e. below –15 deg.C, the filter may also retain crystal deposits formed from natural waxy elements within the fuel itself.

Over time the flow of fuel through the filter will be reduced by the retained particles and if this restriction reaches a critical point, the lack of fuel flowing to the injection system will eventually promote engine misfiring, stalling and even non-starting. This is the point at which the filter is often described as being “blocked”. In diesel fuel injection systems, the fuel also serves as a lubricant and damage can be caused to vital components if the fuel flow is sufficiently reduced by blocked filters. Service intervals are designed to ensure that the filter is replaced before the build-up of dirt etc within the filter becomes excessive.

Sedimenter

Water is often present in diesel fuel, typically caused by condensation in the vehicle fuel tank and in tanks where the fuel is stored prior to reaching the vehicle. Most filter assemblies incorporate drainage systems to both allow water to be removed at regular intervals and to completely drain the assembly when replacing the filter. Water collecting in the system will damage the injection system components by promoting corrosion and this will eventually cause engine running/starting problems.

The difference in specific gravity between water and diesel will result in water sinking to the bottom of the sedimenter with the diesel floating on top. Water can then be drained off, leaving the fuel behind. Some sedimenters contain a switch to detect the level of the water and warn the driver when this water level becomes excessive. A float made of a material which floats on water but not on the less dense diesel fuel, is mounted in the bottom of the sedimenter. As the water progressively sinks to the bottom of the bowl it raises the float until it comes into contact with a water level warning switch. This completes an electrical a circuit to illuminate a warning light on the instrument panel, indicating to the driver that it is time to drain the water from the sedimenter using the drain cock.

Filter types

Diesel fuel filter construction varies between manufacturers and three main types are in use today:

- paper element type – disposable paper element enclosed within a sealed filter housing or bowl. The housing may be screwed directly to the filter head or secured by a bolt between the housing and the filter head
- cartridge type – disposable, metal cased cartridge screwed directly to the filter head
- sandwich type – disposable cartridge with exposed ends, clamped between the filter head and sediment bowl by a long bolt.

Priming pumps

Should the vehicle run out of fuel or when components such as filters are removed/replaced, it may be necessary to prime the system before the engine can be restarted. Air in the system will often prevent fuel being drawn towards the engine, preventing it starting. On vehicles where an electric pressure pump is fitted between the tank and the filter this is not usually necessary as simply turning the pump on with the ignition will bleed the system. On other vehicles, a manually operated priming pump is fitted so that air can be bled out through bleed points normally incorporated into the filter head and the fuel injection pump. The pump is operated with the bleed valves open one at a time until fuel is drawn through the system. Once fuel emerges through the bleed valves they are closed, ensuring that only fresh fuel is left in the system.

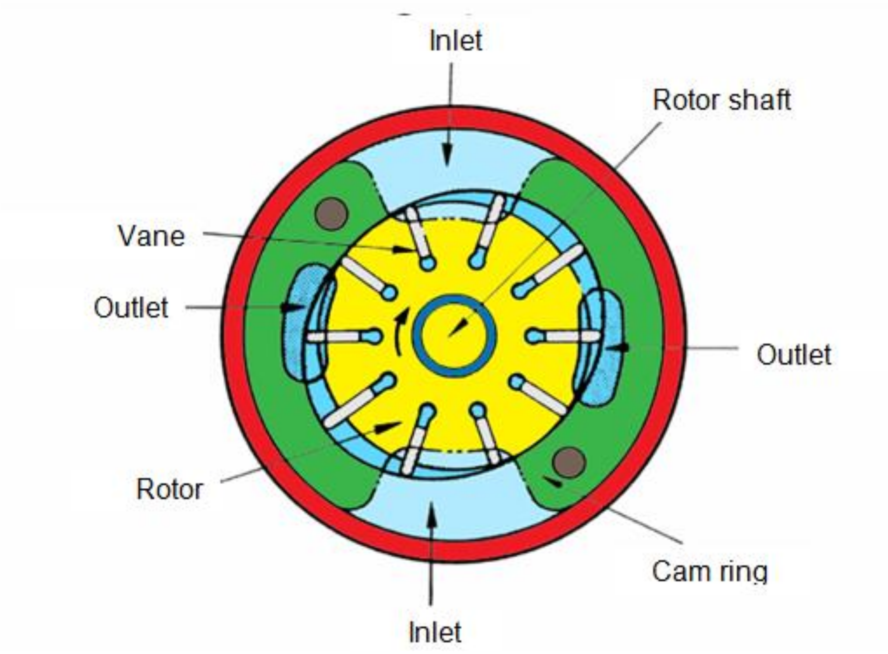
Fuel feed pumps

As previously mentioned, due to the position of most fuel tanks, fuel pumps are required to transfer the fuel from the tank to a secondary, high pressure injection pump so it can deliver it to the engine. Pumps that draw fuel from a position between the main filter and the high-pressure injection pump itself are often called scavenge, vacuum or lift pumps and those that are fitted closer to, or even inside the tank are generally known as feed or pressure pumps.

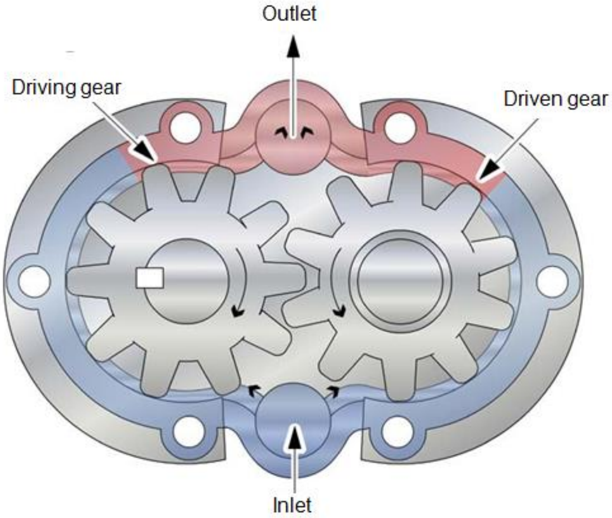
Lift pumps are normally driven by the engine, often being incorporated within the high-pressure injection pump. Pressure pumps are usually remote from the engine and are typically driven by electric motors. In some vehicles, both a remote pressure pump and a lift type feed pump within the high-pressure fuel pump assembly may be used.

Vane type feed pump

The vane type pump uses a rotary action. As the rotor shaft rotates, the force of inertia moves the vanes outwards to the inside face of an oval shaped cam ring. The vane tips seal against the ring, forming a number of pockets which can trap fuel, moving it around with the rotor. As the vanes pass the fuel inlet port, fuel is drawn in and becomes trapped in these pockets. Further rotation carries the fuel along until the vanes reach the fluid outlet ports and the fuel is forced out under pressure into the rest of the fuel supply system. This type of pump is often incorporated within the high-pressure injection pump assembly.



Gear type feed pump

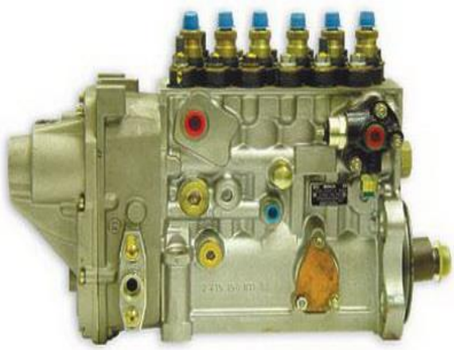


The gear type pump is similar to a vane type pump but contains less moving parts. The driving gear teeth are engaged with those of the driven gear and the two rotate together but in opposite directions. The gears are a very close, sliding fit with the pump housing and are sandwiched between the housing end plates. Fuel is drawn into the gear housing from the inlet port and becomes trapped between the teeth on the gears and the housing. The fuel moves around the housing in these pockets and is forced out under pressure when it reaches the outlet port. The tightly fitting teeth of the gears act as a non-return valve in the centre of the pump housing, preventing fuel passing back towards the inlet port.

Diesel Injection Pumps

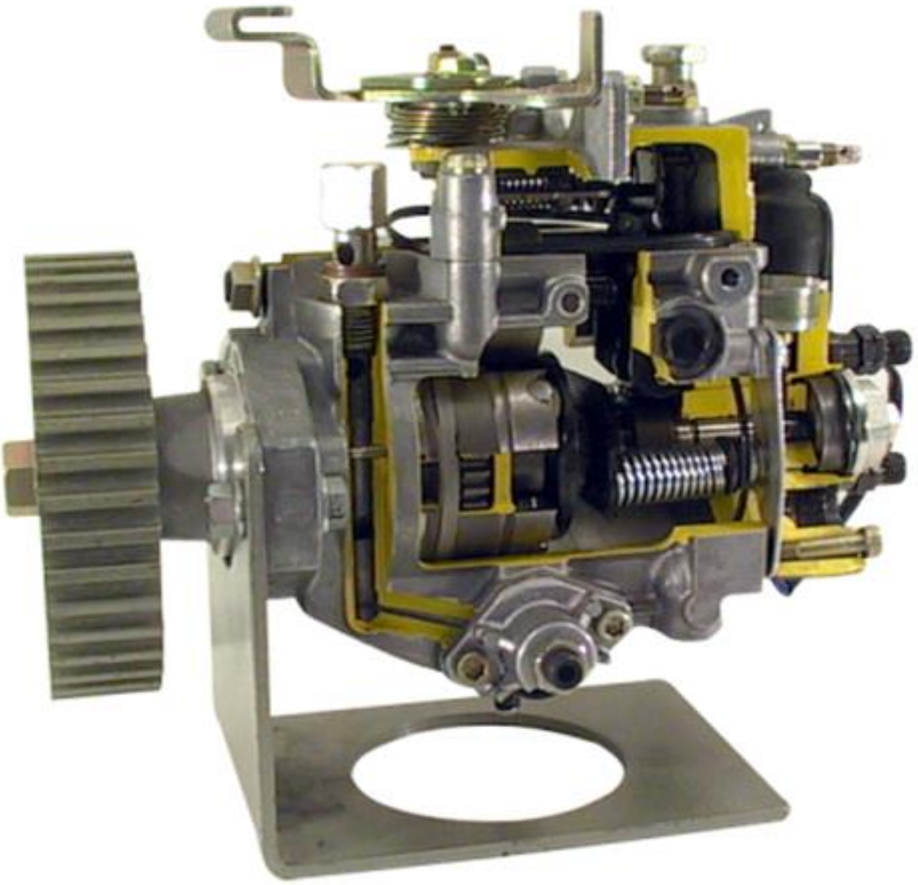
Fuel is initially delivered under low pressure to the engine mounted, high pressure diesel fuel injection pump. It is the job of this pump to increase the fuel pressure to very high levels and distribute this high-pressure fuel to the individual engine cylinders at the correct time. The two commonly used types of injection pumps are:

- the Rotary or Distributor type
- the In-line type.
- The common rail pump



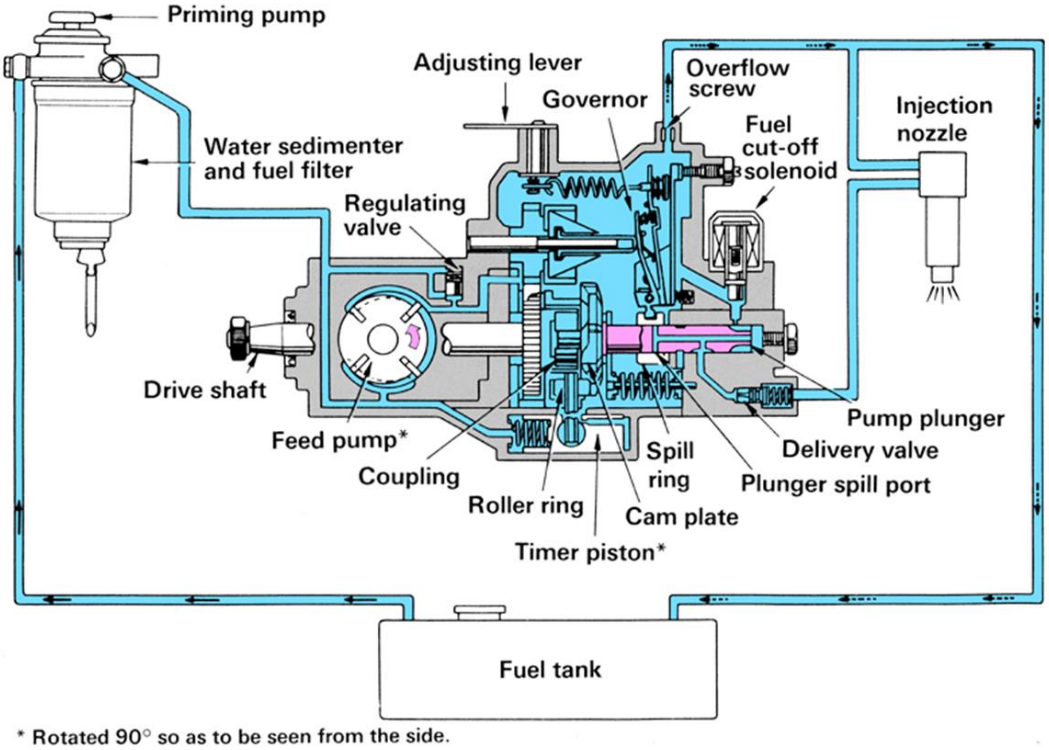
Rotary injection pump

A rotary type fuel injection pump is a relatively simple design. This type of pump is usually used in high-speed, light vehicle diesel engines. Its rotary description is derived from the rotating action which is used to produce the high pressures required as well as distributing the fuel between the injectors in each engine cylinder. It is sometimes known as a distributor type pump.

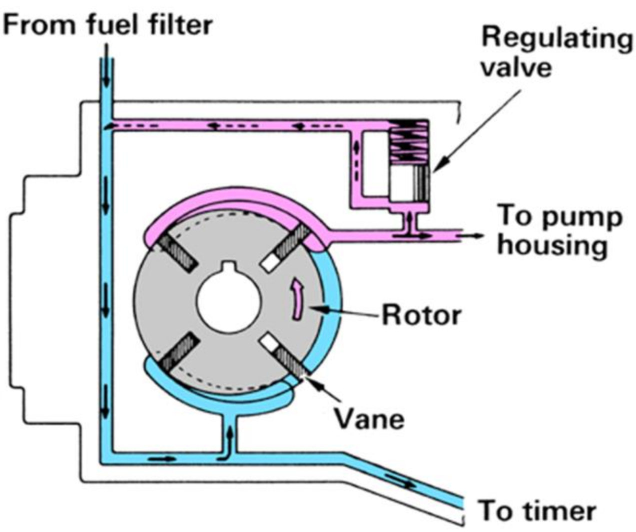


Rotary injection pump components

Feed pump

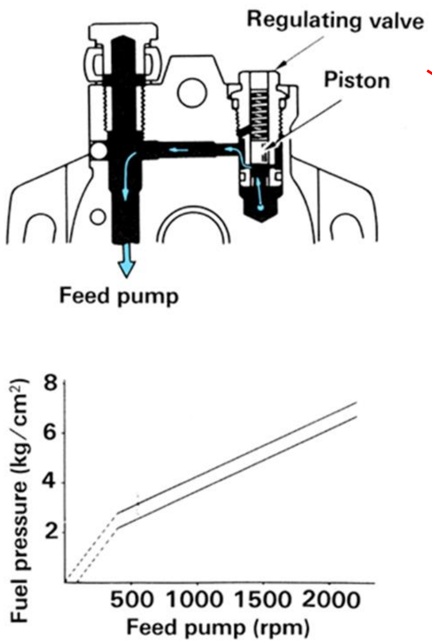


The feed pump in a rotary fuel injection pump is normally a vane type which draws fuel from the tank through the filter and water sedimenter and delivers it to the inner pump housing. The feed pump produces pressures between zero and 10 bar and fuel pressure increases with engine speed to ensure that sufficient fuel is always available. This changing pressure also has an effect on the injection timing. Fuel continuously flows through the pump; lubricating the working parts within the pump housing and keeping them cool. Any excess fuel is recycled back to the fuel tank. The feed pump drive shaft is driven by the crankshaft which rotates at half engine speed.



Pressure regulating valve

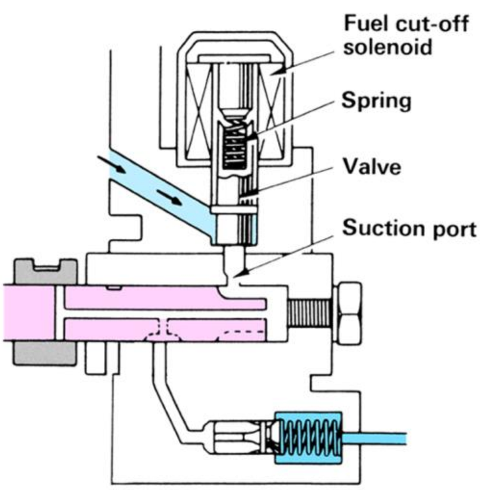
This valve controls the feed pressure inside the pump assembly. The valve regulates fuel pressure in proportion to engine speed. As the engine speed increases, so does the fuel pressure. The photograph below shows a cross section of the feed pump housing and the chart shows the pressure build up in proportion to the speed of the pump.

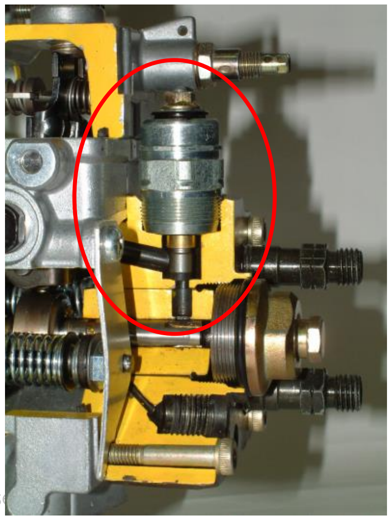


REGULATING VALVE

Fuel cut-off solenoid

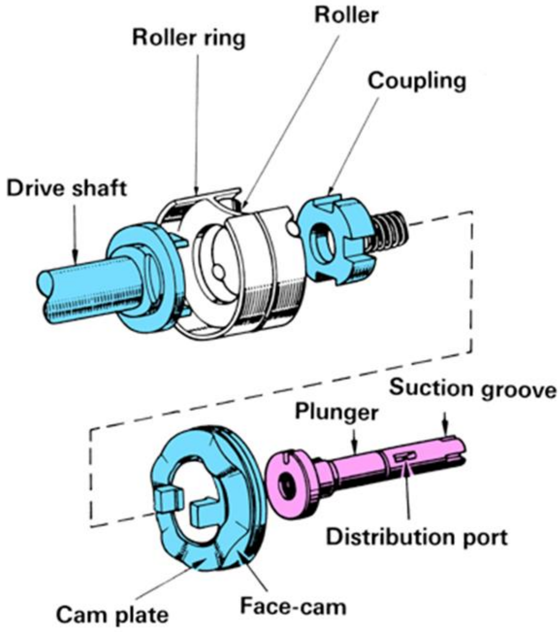
The fuel cut-off solenoid shuts off the fuel supply to the pump plunger when the engine is switched off. Before electric solenoids were utilised, a cable operated valve was used to turn off the fuel and stop the engine. When the ignition is turned on the solenoid valve opens up the suction port, allowing fuel to reach the high-pressure injection plunger. As long as the ignition is on this valve remains open. When the ignition is turned off the valve closes off the suction port under spring pressure.





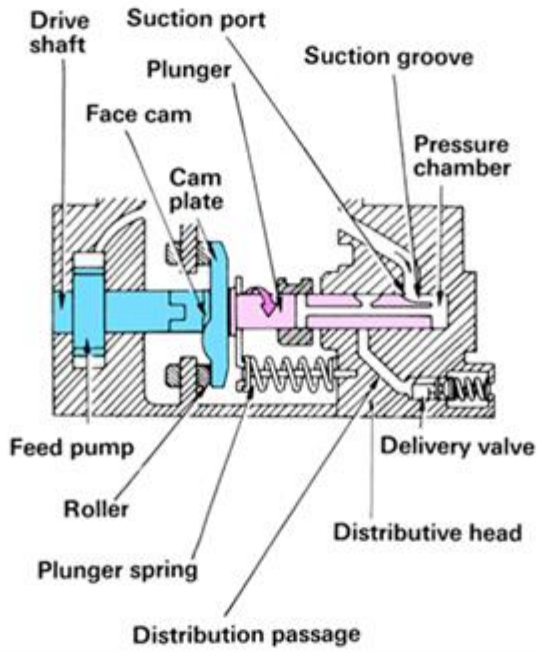
Plunger and Cam plate assembly

The plunger and cam plate are responsible for the delivery of fuel under high pressure to the injectors. The cam plate and plunger are keyed together to the rotary pump's drive-shaft and linked by a floating roller ring. This assembly rotates with the pump shaft and at the same time, the cam acts on the plunger to move it back and forth in a reciprocating piston type action. The roller ring is mounted in the pump housing and does not rotate with the driveshaft. It is however, able to rotate through an angle of up to approximately 12° and is used to advance or retard the injection timing. This function will be covered in a later section.



Plunger and distribution head

As mentioned in the previous paragraph, the plunger rotates through 360° and reciprocates (left and right in the illustrations) at the same time. The rotation is provided by the drive shaft and the cams rising over the rollers in the semi-fixed roller ring push the plunger forward. The plunger return spring pushes the plunger back to its starting position. The plunger is drilled through the centre and has four suction grooves positioned at 90° to one another at the distribution head end, each connected to the centre drilling.



A distribution port and spill port are also machined in the plunger. A sliding, adjustable position spill ring cuts off the spill port during suction and delivery. The position of the spill ring varies the quantity of fuel injected, controlling engine speed (see governor section)

The plunger slides back and forth within the distribution head casting. In a four-cylinder engine, the distribution head has four distribution passages (1 per injector) and a suction port which creates a passageway for the fuel to be drawn from the pump housing.

Fuel delivery process

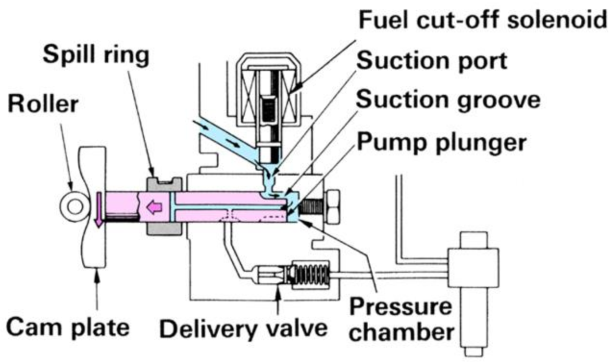
The movement of the cam plate and plunger controls the fuel delivery process and its operation can be described in four distinct stages:

- suction
- delivery
- termination
- equalization.

Suction

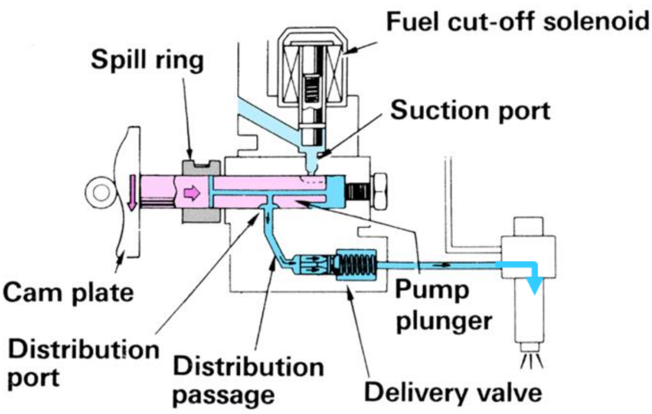
During the suction phase the plunger moves backwards (left in the diagram) under pressure from its return spring. At the same time, one of the rotating plunger's suction grooves aligns with the suction port and draws a charge of fuel into the pressure chamber.

At this time, the spill port is sealed off by the spill ring.



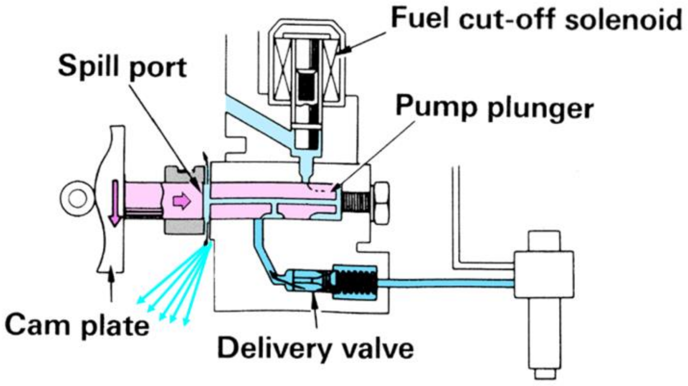
Delivery

As the plunger rotates, the suction port is closed and the spill port remains sealed off. Fuel is now trapped in the plunger bore. At this point the cam on the cam plate causes axial movement of the plunger, pushing it forward (right) applying pressure to the fuel trapped in the plunger bore. With the plunger still rotating, the distribution port aligns with a distribution passage to one of the injectors. The plunger action raises the fuel pressure is raised to a level sufficient to force open the delivery valve (up to 700 bar). A charge of fuel is now delivered the engine's combustion chamber via the high-pressure fuel pipe and injector



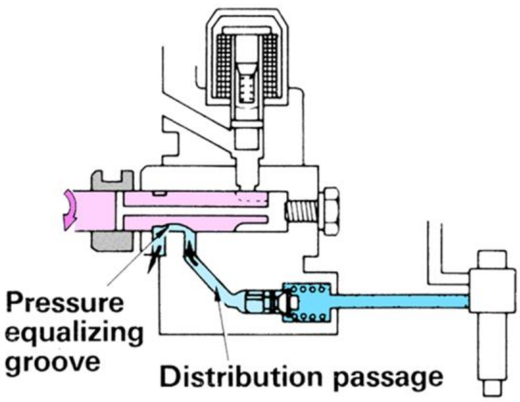
Termination (end of injection)

During the termination phase the plunger continues to move forward until the cam on the cam plate has reached its highest point. At this position, the spill ring is uncovered and fuel left inside the plunger can leave via the spill port, into the pump housing. The resulting drop in pressure allows rapid closure of the delivery valve. This is the end of injection.



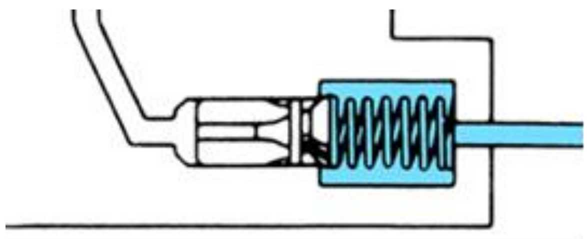
Pressure equalisation

The rapid action of the delivery valve closing produces a small amount of pressure in the distribution passage. If this pressure is not relieved, it may result in early opening of the valve at the next injection. Further rotation and backwards movement of the plunger aligns a pressure equalization groove in the plunger with both the distribution passage and the pump housing. This equalises the pressure between the distribution passage and pump housing in readiness for the next cycle.



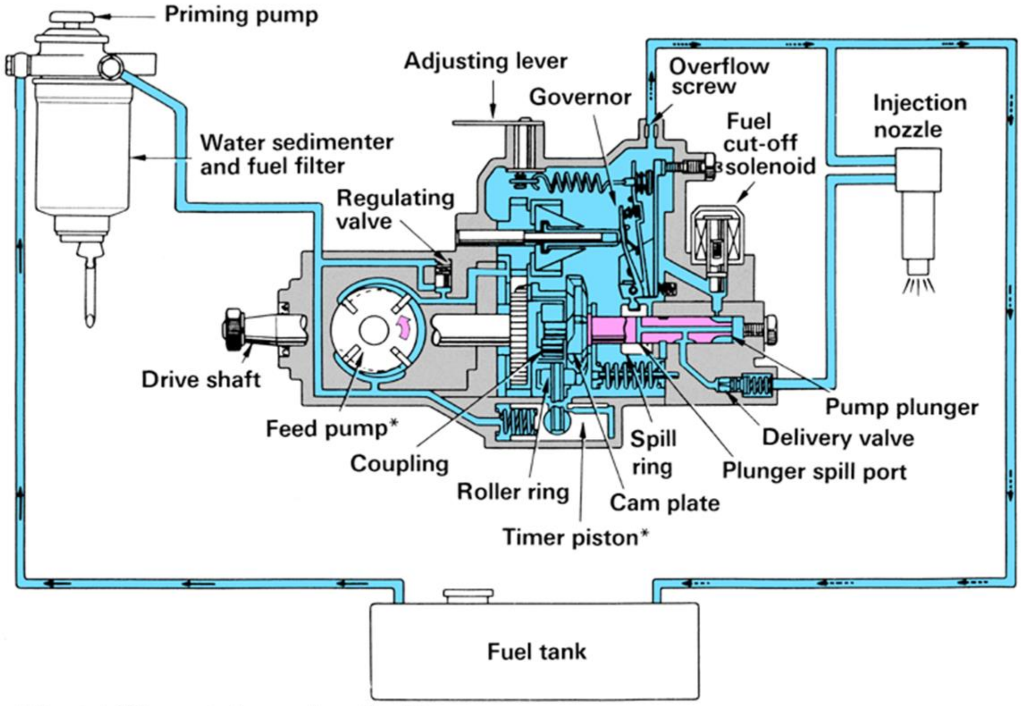
Delivery Valves

The delivery valves operate in conjunction with the plunger to provide the injectors with fuel, ensuring that the fuel is delivered to the injectors accurately by rapidly opening and closing the fuel lines to the injectors. The delivery valves ensure that the high-pressure fuel lines remain fully primed and pressurised with fuel at all times. Fuel forced into the fuel lines through the delivery valves produces a shock wave throughout the fuel already in the high-pressure lines which subsequently forces fuel through the injectors.



Rotary pump automatic timing

Basic injection timing is determined when the pump is mounted on the engine. These timing settings are often referred to as static timing**.** In addition to this static setting, many manufacturers incorporate automatic or dynamic timing devices that retard or advance injection in order to match all engine speeds. Correct timing of the injection in diesel engines is critical to ensure smooth running, good economy, adequate power and low emissions under all load and speed conditions.



* Rotated 90° so as to be seen from the side.

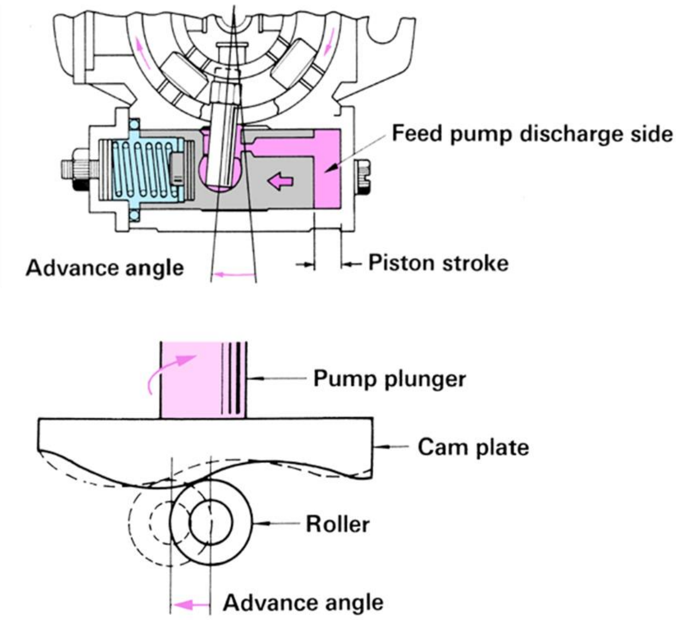
Fuel needs to be injected at precise moments to ensure that combustion occurs correctly. As the engine speed increases it is necessary to inject the fuel earlier in the cycle. This is because fuel takes time to get into the right place within the cylinder and burn. Diesel injection pumps incorporate devices to advance (inject earlier) or retard (inject later) the injection timing.

The automatic timing device incorporated into the rotary pump utilizes fuel feed pump pressure to adjust the injection timing, the purpose being to inject fuel earlier or later to improve engine power and/or emissions. The feed pump supplies fuel under regulated pressure to the pump housing but also to the timer piston situated in the base of the injection pump assembly directly below the roller ring.

The timing device consists of a piston mounted at right-angles to the pump driveshaft. The piston slides in a fuel filled bore and is biased towards the retarded position under spring pressure. The piston is connected to the roller ring by a slide pin which acts as a lever to turn the ring when the piston moves within its bore.

Timing variation

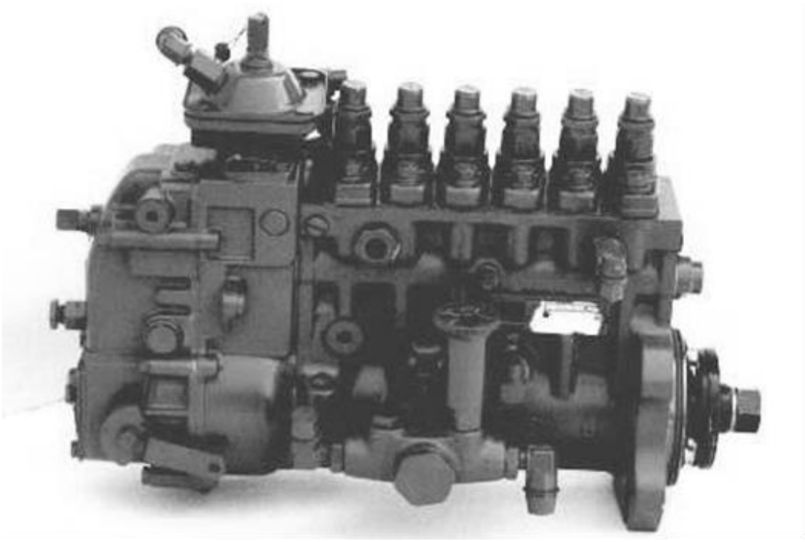
As the engine speed increases, so does the pressure produced by the feed pump. The increased pressure acts on the back of the timer piston and moves it in the direction shown in the diagram. The slide pin moves with the piston which turns the roller ring and its rollers in the opposite direction to the rotation of the cam and plunger assembly. This has the effect of making the pumping stoke occur earlier i.e. advancing the injection timing.

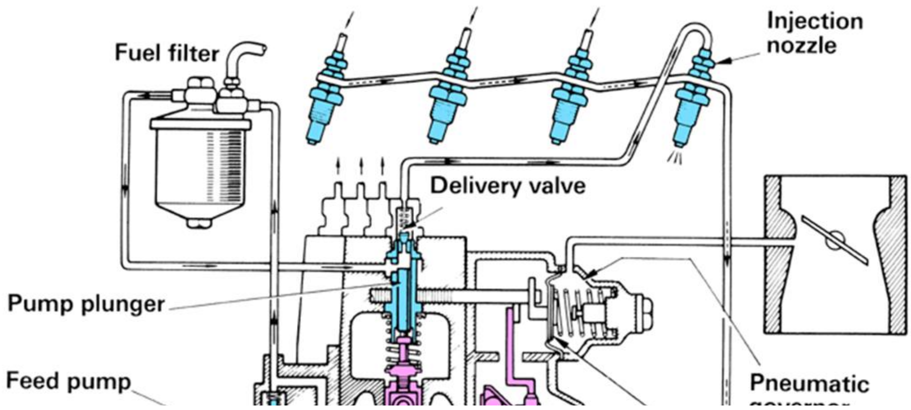


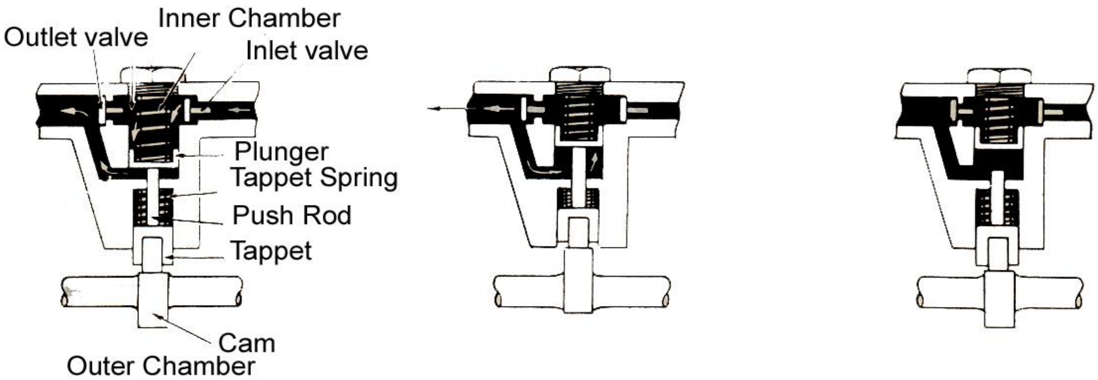
A reduction in pump speed results in a drop-in fuel feed pressure; this allows the timer spring to reassert itself and move the slide pin and ultimately the rollers on the roller ring, in the same direction as the cam and plunger assembly thus retarding the injection timing.

Inline pump

Whereas the rotary pump uses a single plunger to deliver fuel through several distribution channels in the pump housing, an in-line pump utilizes several plungers operated by a camshaft, one plunger for each cylinder. In a four-cylinder engine, the injection pump will contain four plunger assemblies. The same camshaft that operates the plungers also operates the feed pump.







FEED PUMP OPERATION

Mechanical Feed Pump (Plunger Type)

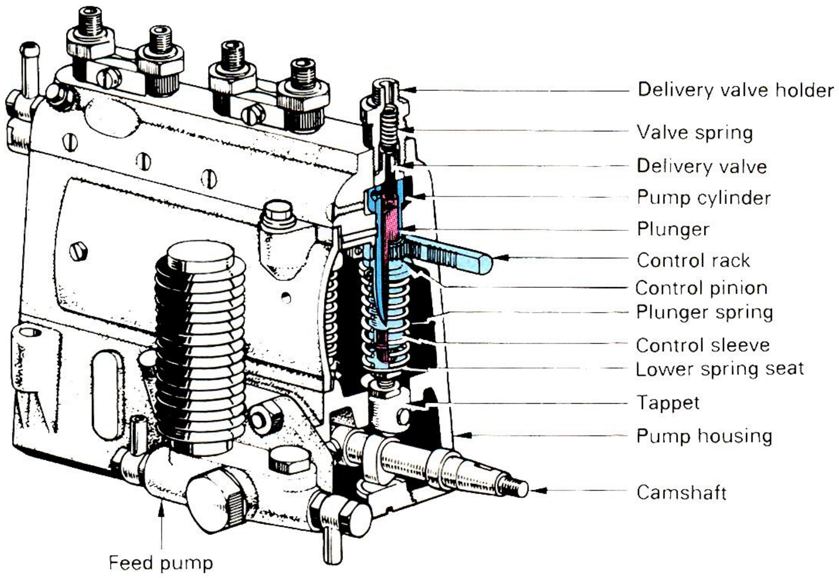
The feed pump is normally mounted on the in-line injection pump casing and is operated by the pump camshaft. This lift pump draws fuel from the tank and delivers it to the high-pressure pumping elements within the injection pump at up to 2.5 bar pressure. It is designed to operate at speeds relative to the engine speed, i.e. at low speeds the pressure and flow is low; at higher speeds the pressure and flow increases.

When the cam is at the minimum lift position, the plunger is forced down by its spring causing a depression in the inner chamber, closing the outlet valve. This depression also forces the inlet valve to open, allowing fuel to flow from the fuel tank past the inlet valve to the inner chamber.

At the same time, fuel waiting in the outer chamber is forced by the back of the plunger, through the outlet to the injection pump, after the closed outlet valve. As the camshaft lobe turns further it lifts the plunger to the maximum lift position increasing the pressure of the fuel which closes the inlet valve preventing fuel from being forced back to the tank. The same pressure opens the outlet valve and forces fuel to the outer chamber as well delivering fuel to the injection pump.

The purpose of two pumping chambers is twofold. Firstly, because the fuel is pumped to the injection pump by the plunger moving in both directions a smooth flow of fuel is produced, reducing pulsations. Secondly, at high engine speeds a large quantity of fuel is delivered to the injection pump. If the throttle is closed, reducing demand for fuel at these engine speeds there could be too much fuel pressure available within the injection pump housing, risking damage to the feed pump. Should the fuel quantity and pressure within the injection pump housing become excessive, this pressure will be equally felt in both the inner and outer chambers. Equal pressure closes the outlet valve as well as holding the plunger in the upper position, causing the pump to "freewheel" and flow ceases. The camshaft continues to rotate but it has no effect on the pump.

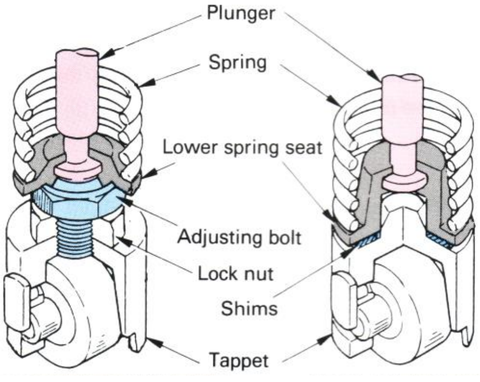
Pump Housing



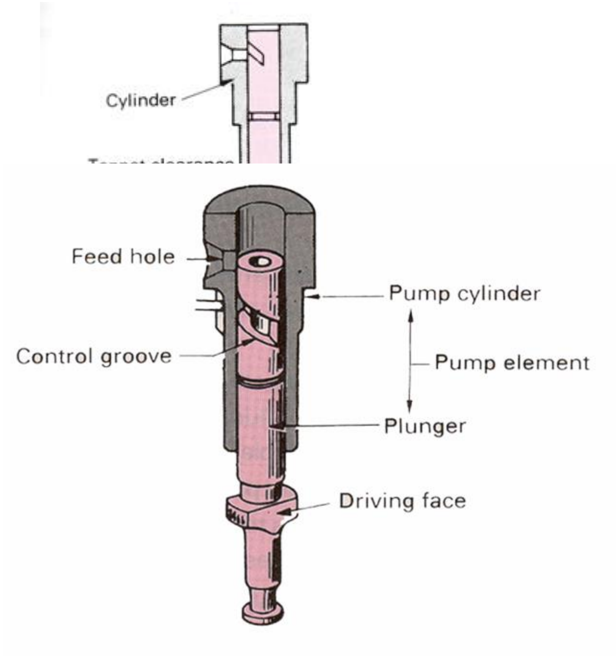
INJECTION PUMP CONSTRUCTION

The injection pump housing is normally made of cast aluminium and houses the pumping and governor mechanisms and the engine driven camshaft. The camshaft has one cam lobe for each engine cylinder which operates tappets to lift the high-pressure pumping element plungers. A return spring ensures that the plungers remain in contact with the cam lobes.

The diagram on the right shows two types of tappet assemblies with different adjustment methods.

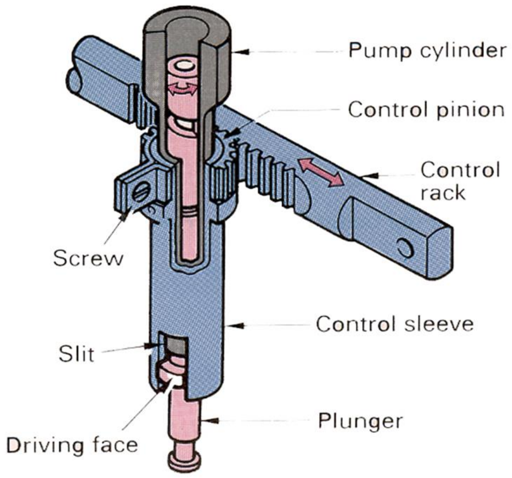


The pump cylinder in which the plunger reciprocates is fixed inside the pump housing beneath the delivery valve housing. ***Pumping elements***



The pump cylinder has a fuel feed hole at the top which aligns with a passageway in the injection pump housing and through which fuel is drawn during the suction phase. The plunger has a blind drilling through its centre and a helical control groove machined on its surface to regulate the volume of fuel injected.

The pump cylinder and plunger assembly fits inside a control sleeve that can rotate. A small pinion gear attached to the control sleeve engages with a toothed control rack which runs the length of the injection pump assembly, engaging with all the pumping elements. When the control rack moves forward or backward, the control sleeve rotates the plunger.



Fuel delivery

The following sequence describes how fuel is pumped to a single injector during one rotation of the pump camshaft.

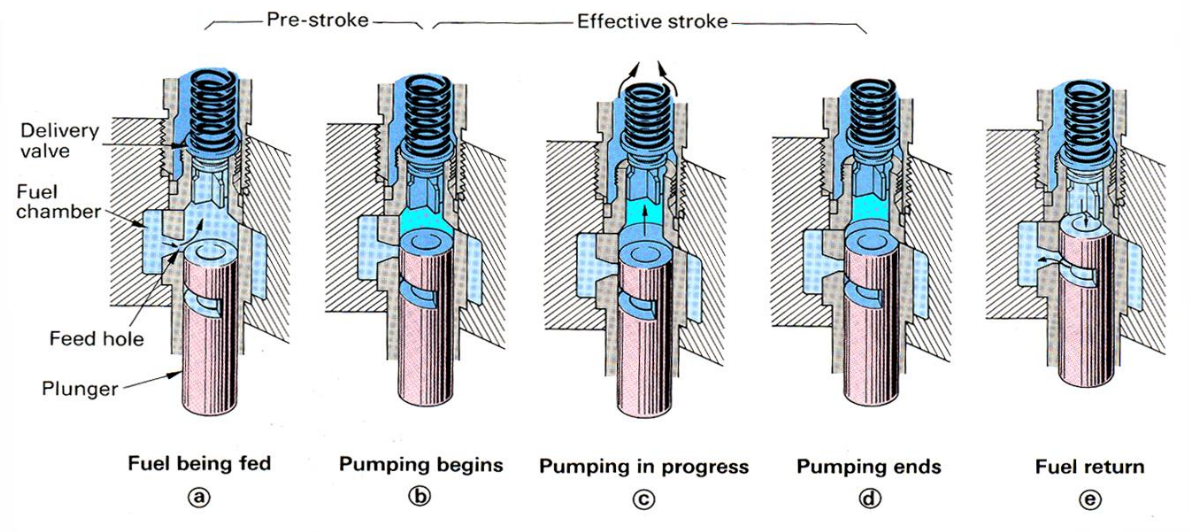
a. The plunger is at the bottom of its stroke. Fuel from the feed pump has forced fuel into the cylinder through the feedhole via the fuel chamber and the cylinder is full.

b. The rotating camshaft starts to lift the plunger which passes the feed hole, sealing it off. Fuel is now trapped within the plunger and under pressure; it is at this point that pumping begins.

c. The plunger continues to rise and when the pressure built up is sufficient to overcome the spring behind the delivery valve, the valve is forced open and a charge of fuel enters the high-pressure fuel line to the injector in the engine cylinder.

d. When the top edge of the control groove aligns with the feedhole, any fuel remaining in the plunger begins to escape into the fuel chamber and the pressure in the pumping cylinder drops.

e. The plunger continues to rise, when the control groove is fully aligned with the feedhole the pressure in the cylinder drops even further, and the spring in the delivery valve re-asserts itself, closing the valve and injection stops.



It is important to note that the total pump stroke is extremely short. From its lowest position (a) to the end of the stroke (e) the plunger may move no more than 5mm in many cases.

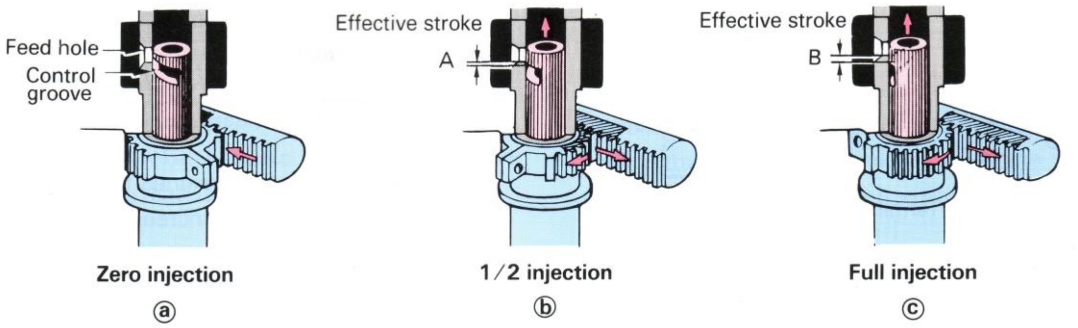
Adjustment of fuel quantity

The quantity of fuel that is distributed to the injectors determines a diesel engine's speed and power output. In an in-line pump, movement of the control rack determines the quantity of fuel by rotating the individual pumping elements. This changes the "effective" stroke of the plunger whilst the "actual" stroke always remains fixed by the design of the lifting cam. The following sequence shows how the fuel is regulated.

a. In this case the plunger is just starting to rise to rise. The control rack is fully to the left and the control sleeve and its plunger are rotated fully anti-clockwise. In this position, the highest part of the helical groove in the plunger is already aligned with the bottom edge of the feed hole and as the cam lifts the plunger, fuel is forced back into the fuel chamber through the feed hole. This means the pressure in the pump cylinder is insufficient to open the delivery valve and no fuel is injected so the engine will not run. In this condition the effective stroke is zero.

b. In this position the control rack has moved partly to the right and the control sleeve and plunger has turned approximately 70 degrees clockwise or about half of its total movement. It can be seen that the plunger can now rise further before the helical grove becomes aligned with the feed hole, again forcing fuel back into the feed chamber. During this longer effective stroke, fuel is pressurised and forced into the high pressure fuel lines to the injector.

c. When the control rack has moved fully to the right, the control sleeve and plunger is rotated fully clockwise. The plunger can now rise much further before the helical groove reaches the feed hole and as a result more fuel in injected. In this case the effective stroke of the plunger is at its maximum and maximum fuel is being injected.



It should be noted that the position of the control rack can be adjusted to any position between zero and maximum, depending on the driver's demand and any intervention of the governor.

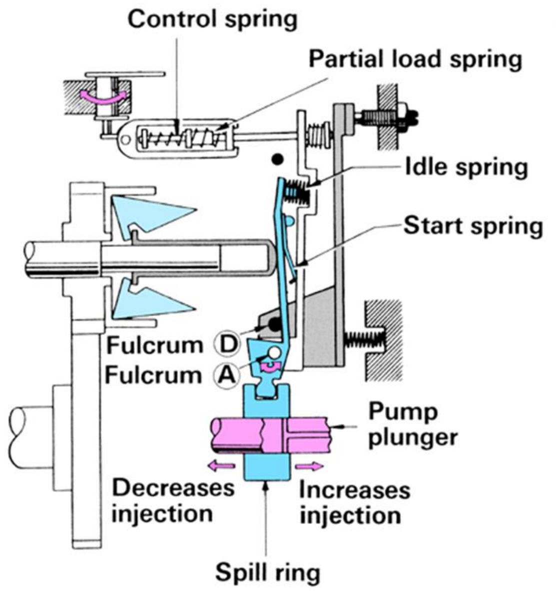
Governors

All automotive diesel injection engines use a governor, mainly to control the volume of fuel injected in order to limit the engine's maximum speed. The limited maximum speed of a diesel engine is determined primarily by the effectiveness of combustion which depends a number of physical factors, including how fast diesel fuel can actually burn. If the fuel does not burn properly, power will be lost and emissions increase.

Once an engine reaches a speed where the combustion process starts to deteriorate, there is little point adding extra fuel in the hope of increasing the engine's speed, the only result of which would be more misfiring and higher exhaust emissions. The governor is designed and adjusted to limit the engine's speed to a point just below that at which combustion quality deteriorates. At this maximum limit, the maximum stress put on an engine at high speeds is also reduced, preventing damage to components.

Diesel engine governors are designed to control idling speeds as well as maximum speeds. If the idle speed is not controlled, diesel engines have a tendency to surge or "hunt". There are a number of different types of idling and maximum speed governors, operating mechanically, pneumatically or a combination of both methods. Increasing use is now being made of electronics to control diesel pumps.

Mechanical governor



The diagram opposite illustrates the components that make up a typical mechanical governor, in this case as fitted to a rotary injection pump.

A governor shaft is driven by the injection pump drive shaft via a gear train with a 1:1.6 ratio. (Every rotation of the pump drive shaft results in 1.6 rotations of the governor shaft). This increase in shaft speed improves the sensitivity of the governor. The governor shaft rotation is detected by four flyweights that use centrifugal force to transmit this force to a control lever via axial movement of the governor sleeve.

The accelerator cable is connected to a control spring assembly at the injection pump. This assembly is key to the operation of the governor. A damper spring and idle spring work in conjunction with one another to prevent hunting. Movement of the governor lever assembly adjusts the position of the spill ring on the plunger. This will either prolong or shorten the delivery stroke of the plunger, thereby increasing, or decreasing the volume of fuel that is supplied to the injectors.

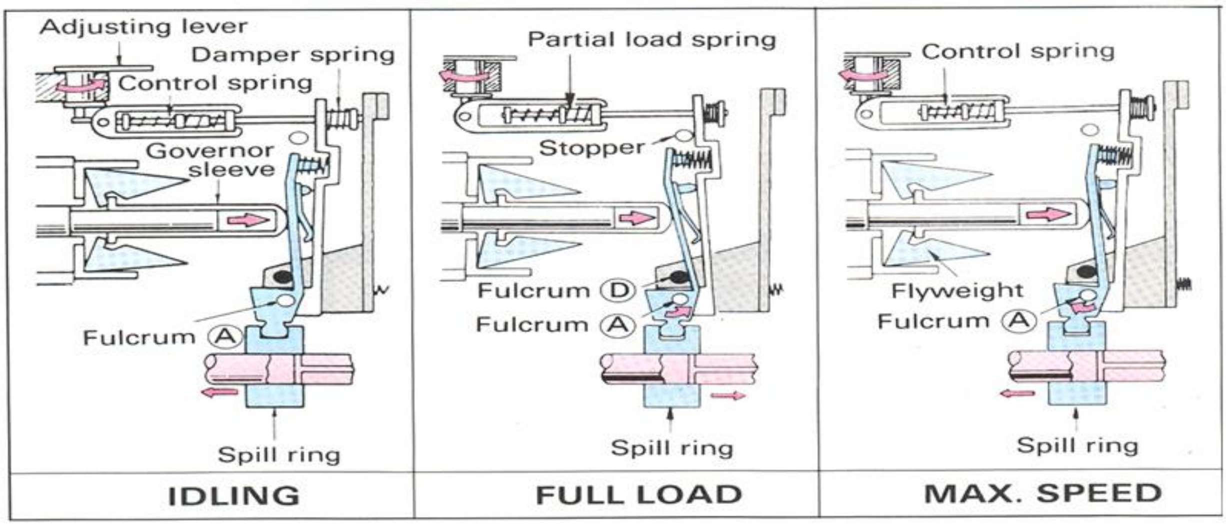
Minimum/Maximum speed governor operation

- Idling – with the accelerator in the idle position the control spring is under no tension and the tension lever is balanced between the idle and damper springs. The tension on each of these springs is constantly changing due to the pressure applied by the governor sleeve, against the control lever by the action of the spinning governor flyweights. Any hunting (slight changes in engine speed) is immediately reflected in the position of the governor sleeve.

  With the control lever balanced in this position, fluctuating slightly around fulcrum "A", the spill ring is also sliding slightly along the pump plunger. The position of the spill ring affects the point at which injection ends, controlling the quantity of fuel injected (see rotary pump fuel delivery process).

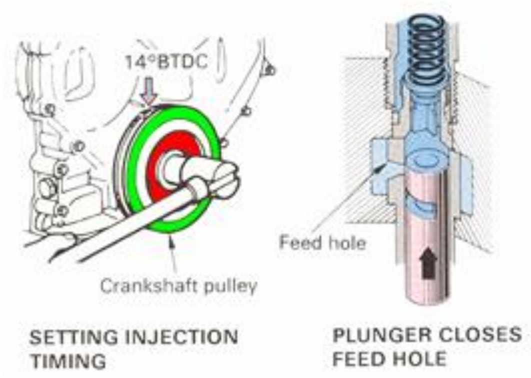
- Full load – in this condition the accelerator is fully depressed but the engine speed is not yet at maximum. The tension lever is hard against the stopper. As the engine speed is not yet at maximum, the flyweights are not producing enough pressure on the governor sleeve to push the control lever back. This results in the spill ring being held fully to the right in the maximum fuel position.

- Maximum speed - When the engine reaches maximum speed the thrust of the flyweights forces the governor sleeve fully to the right against the control lever and tension lever. This extreme pressure overcomes the control spring tension, forcing the tension lever and control lever to pivot about fulcrum "A", moving the spill sleeve to the left. This has the effect of reducing the effective stroke of the pump plunger and therefore the quantity of fuel injected.



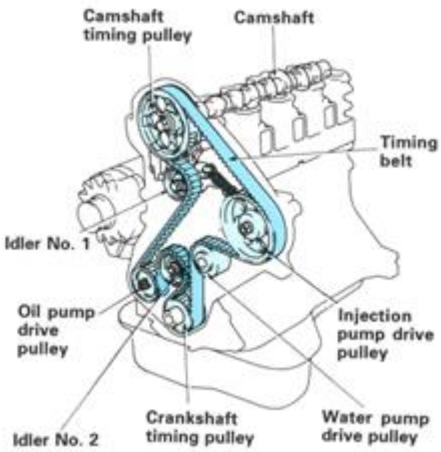
Injection Timing

Correct timing of the injection in diesel engines is critical to ensure smooth running, good economy, adequate power and low emissions under all load and speed conditions.

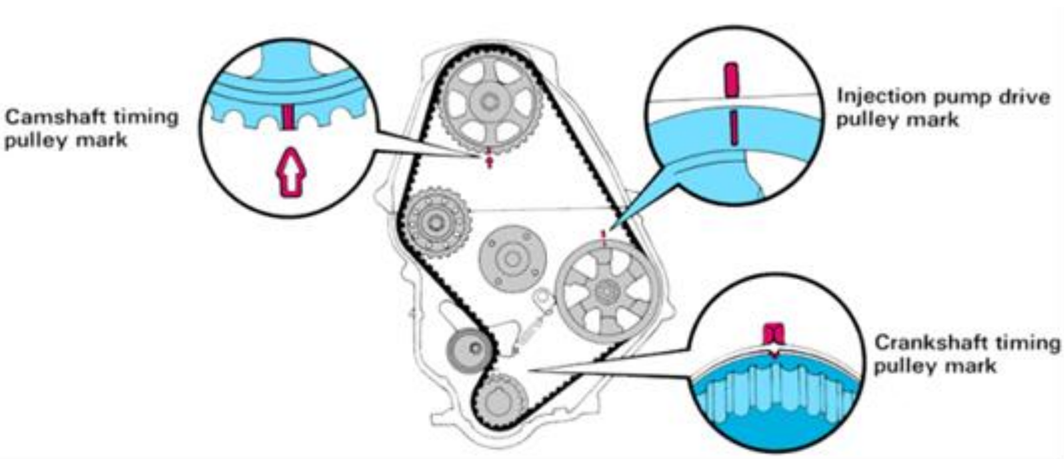


Fuel needs to be injected at precise moments to ensure that combustion occurs correctly. As the engine speed increases it is necessary to inject the fuel earlier in the cycle. This is because fuel takes time to get into the right place within the cylinder and burn. As has been seen, diesel injection pumps incorporate devices to advance or retard the injection timing.

These automatic timing adjustments need a basic starting point, at which no automatic adjustment takes place. The basic adjustment values are determined by the engine manufacturer and these specifications are used when the injection pump is fitted to the engine.



The specifications normally describe how many of degrees of crankshaft rotation before or after the piston Top Dead Centre, fuel should start to be injected. Marks on the crankshaft pulley, engine casing and the injection pump drive pulley are normally provided and accurate alignment of these marks is essential.



Common symptoms of incorrect timing injection

As the engine speed and load changes constantly, timing devices are constantly retarding or advancing the timing of injection and governors are adjusting the fuel volume. The combination of both these systems working correctly will result in a smooth-running diesel engine. When faults are reported however, there are a few simple visual and audible indications that can be utilised to diagnose faults. Almost all engine running faults result in loss of power and/or excessive smoke emissions, although the fault diagnosis differs depending on the combustion/injection system used i.e. direct or indirect injection.

Diesel engines rely on changes in fuel supply to vary the engine speed and power output. Although this may seem a slightly hit or miss approach, the process is actually very accurately controlled. This means that diesel engines tend to run very well when they are in good condition but when faults exist they deteriorate noticeably.

Black exhaust fumes

Black smoke contains incompletely burned fuel (carbon) resulting from incomplete combustion because the mixture is excessively rich.

This can be caused by:

- too much fuel – excess fuel cannot burn without extra air as well
- too little air – similar to above
- fuel injected too early or overly advanced in an indirect injection engine – if the fuel is injected before the combustion pressure and temperature is adequate the mixture will not burn properly
- fuel is injected too late or overly retarded in a direct injection engine – the injected fuel burns too quickly as the combustion pressures and temperatures are too high during injection, using up most of the air in the cylinder. This leaves some fuel unable to burn due to a lack of air

White exhaust fumes

This symptom tends to occur before the engine has fully warmed up and injected fuel is partly but insufficiently heated, resulting in condensation and water vapour emissions from the exhaust

This can be caused by

- fuel injected excessively late (retarded) in an indirect injection engine – the pressure in the swirl chamber is dropping and fuel is exhausted unburned

- fuel injected too early or overly advanced in a direct injection engine – if fuel is injected before the pressures within the cylinder are sufficient fuel will actually cool the cylinder walls, evaporating as it does so, again resulting in evaporation and water vapour emissions.

- Water mixed with fuel – contamination or water entering the combustion chamber

- Compression pressure too low – worn engine

Loud Diesel knocking

If a large amount of fuel is injected too early it will cause an excessively rapid rise in combustion pressure. Normal combustion in diesel engines produces a quick but progressive rise in pressure which gives the diesel engine its characteristic low speed “pulling power”. Excessively rapid rises in pressure degrade this effect and produces heavy knocking. This knocking is in addition to the knocking normally detected in diesel engines when cold.

Common Rail

When common rail arrived in the late 1990s it changed the nature of diesel engines. They were no longer noisy, low powered sluggers, but instead became powerful, quiet, responsive and even more fuel efficient. So how does common rail do this? Well, it's down to the injection pressure and pilot injection. Pilot injection means that a small quantity of fuel is injected into the combustion chamber before TDC. This fuel then goes through the same three phases of combustion. The difference is that because there is only a small amount of fuel involved the initial temperature reduction is lessened, the delay period is reduced and the uncontrolled burn period is reduced. The result of this is a significant reduction in diesel knock. The injection pressures are increased from around 150-190 bar to 1350-2000bar; this means that the fuel can be delivered into the cylinder at a higher pressure and in a shorter time. This promotes atomisation and better combustion efficiency. The systems differ in design from manufacturer to manufacturer and there have been several developments in pressure regulation and injector types but all systems are generally similar in operation. The following description is for the Bosch CP1 fitted to PSA HDI engines, but is similar to other applications.

System overview

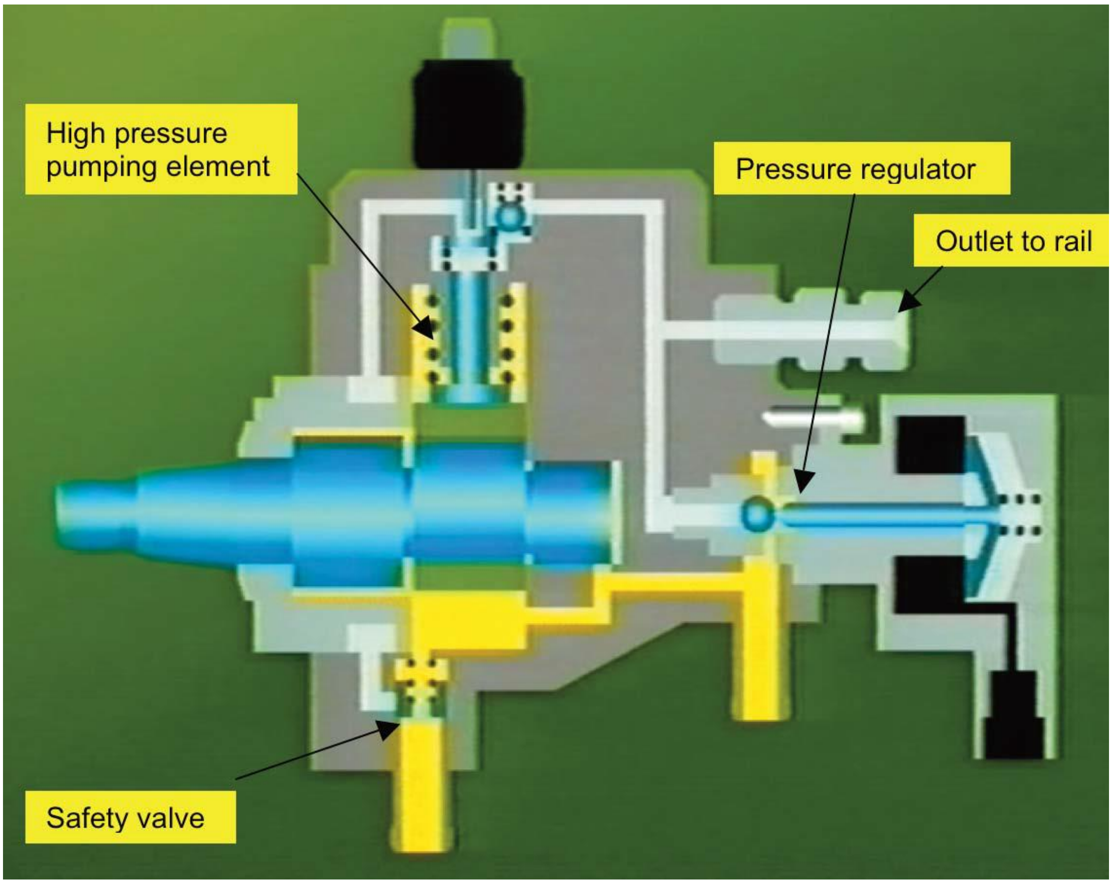
Common rail is a high pressure electronically controlled injection system. The pressure can be modulated independent of engine speed. It comprises of an electric low pressure pump with integral filter, main fuel filter and a high-pressure pump driven by the engine. The high-pressure pump provides a constant flow of fuel to a common rail or accumulator. The rail is in turn connected to the injectors by pipes. Each injector is actuated by a solenoid controlled valve. An ECM controls the fuel pressure, flow-rate and operation of the injectors. Each injector can have several injections per engine cycle and at a variable pressure.

Fuel filter

The fuel filter has a thermostatically controlled inlet divider which can send varying quantities of fuel to the fuel heater situated in the coolant outlet in the cylinder head. This ensures consistent density and viscosity of the fuel.

High pressure pump

The high-pressure pump consists of three pumping elements. The fuel enters the pump via a safety valve. The pressure from the low-pressure pump must be above 0.8bar to lift the safety valve and allow fuel to enter the high-pressure pumping element. The hole in the safety valve allows for lubrication. Fuel enters the pumping element and is pressurised, it then travels down the outlet to the rail. The fuel pressure regulator is a pulse width modulated solenoid, which controls the flow of fuel back to the inlet and thus the fuel pressure in the rail.



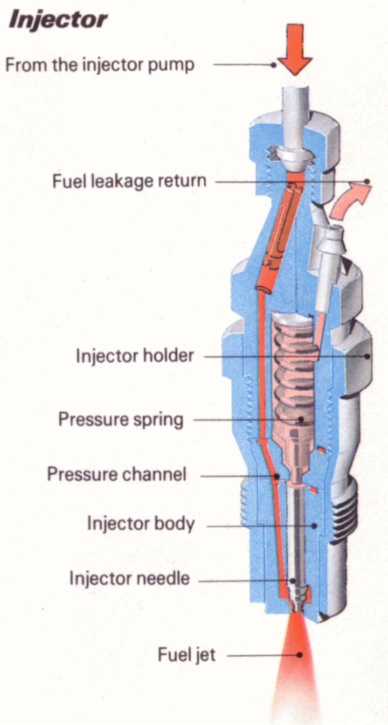
Injectors

Injectors have several functions:

- to build up and maintain very high fuel pressures without leakage
- to allow the fuel to enter the cylinder when the correct pressure is reached
- to atomise the fuel. This makes the fuel burn easier and more cleanly
- to ensure the fuel is sprayed into the cylinder in the correct pattern and direction
- to cut the fuel off quickly and cleanly at the end of injection.

- to seal the combustion chamber

The injectors are connected to the delivery valves on the fuel injection pump by high-pressure fuel pipes. These pipes must sustain extreme pressures and their lengths are carefully calibrated to optimise the injection process. They will normally all be of the same length, regardless of the position of the injectors relative to the injection pump.



The body of an injector can be broken down into two main parts, the nozzle body and nozzle holder. An annular chamber to contain fuel surrounds the nozzle needle at its base and the needle is held closed by the pressure spring. The spring pressure can usually be adjusted using shims.

The whole injector body is filled with fuel which is used for lubrication. Excess fuel returns to the fuel tank via an overflow/spill pipe.

Operation

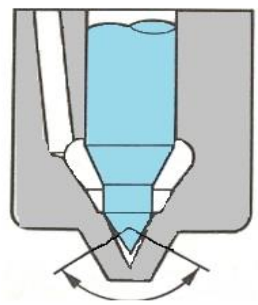
The entire high pressure system is full of fuel at all times, from the injection plunger through the delivery valve and fuel lines to the injector. The pressure maintained in this system is always high but not quite as high as the pressure needed for injection. This reduces any delay in the injection process. Any rise in pressure created by the plunger in the fuel injection pump is therefore felt immediately, all the way to the injector needle.
As the plunger in the injection pump increases, the delivery valve opens fuel is forced into the high-pressure pipes. As fuel in not compressible, this rise in pressure is felt throughout the pipe and injector in the form of a shock wave which rapidly increases the pressure in the injector. Once the pressure is sufficient to overcome the spring tension, the nozzle needle rises and injection takes place. Due to the high pressures involved, the fuel enters the cylinder in the form of a very fine spray. As soon as the injector opens, the pressure in the line drops significantly allowing the delivery valve to close. The lower line pressure now allows the injector pressure spring to re-assert itself, closing the nozzle needle and injection stops.

Injector nozzles

Injector nozzles are generally categorized into two main types, multi-hole type or pintle type.

Multi-hole type

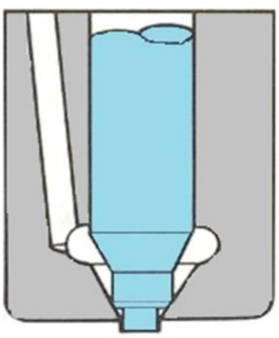
Multi hole type injectors are generally used for direct injection systems where the fuel is injected directly into the engine cylinder. Two or more holes are drilled at various angles, these produce a highly-atomized spray and have a high operating pressure of between 150 - 250 bar.



Multiple hole type

Pintle Type

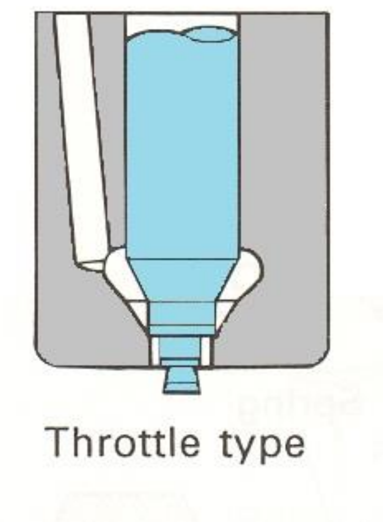
Pintle types are used in swirl chambers in indirect injection engines. These injectors produce a soft spray and like the single hole type, have a low injection pressure of 110 – 135 bar.



Pintle type

Throttle type pintles

Most pintle type nozzles are known as throttle types. The tip of the pintle is stepped and flared. This allows the quantity of fuel injected to vary progressively over the course of the injection cycle.



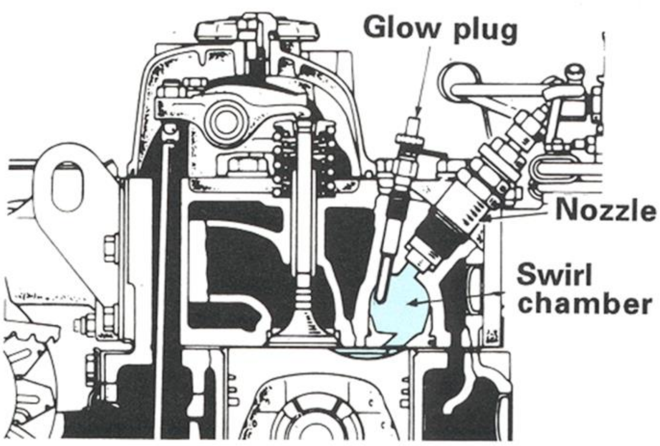
Direct and Indirect Injection

While air is being drawn into the combustion chamber and compressed it is advantageous to create an organized air swirl so that when the fuel is injected it mixes effectively and ultimately combusts properly. Shaping the combustion chamber or creating a pre-combustion chamber connected to the cylinder by a small throat can achieve swirl. The top of the piston crown and the area above it where the valves are located forms the combustion chamber. Swirl can be created on the induction stroke, the compression stroke or during combustion.

Indirect injection

The injector protrudes into a small pre-chamber which is connected to the main combustion chamber by a throat and narrow passageway.

When air in the cylinder is compressed as the piston rises, this hot, pressurised air also swirls into the pre-chamber. As the fuel is injected into this hot air the mixture combusts immediately, expanding back into the main combustion space above the piston. Due to the small size of the pre-combustion chamber, it is not necessary to inject fuel very far but it must be well



atomised. Pintle type injectors fulfil these requirements and are usually used in this type of application.

Advantages of indirect injection compared to direct injection

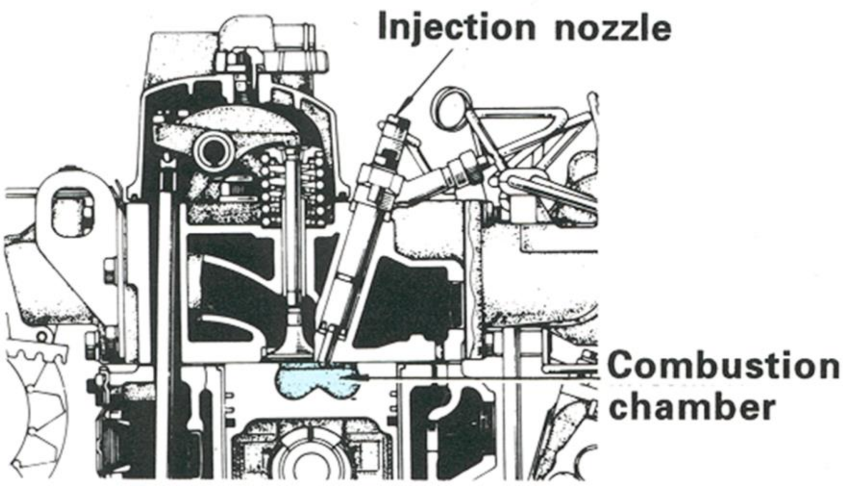
- high rate of swirl over wide range of engine speeds
- does not require expensive, ultra high pressure injection system
- less chance of injector blockage due to self cleaning pintle injectors

Disadvantages

- poor fuel consumption due to lower thermal efficiency
- higher compression ratio required to aid starting
- noisy operation

Direct injection

The tips of injectors in a direct injection engine protrude directly into the combustion chamber. Swirl, produced as air enters the combustion chamber, is created by "lipped" inlet valve seats, masked inlet valves, the design of the inlet manifold and the shape of the combustion chamber itself.



The agitated air is spread over a relatively large area and it is important to ensure that fuel reaches as much air as possible and is not concentrated in a small area. This is the main reason why multi-hole injectors are used in direct injection engines. Fuel is distributed widely throughout the combustion chamber promoting even, rapid combustion.

Advantages of direct injection compared to indirect injection

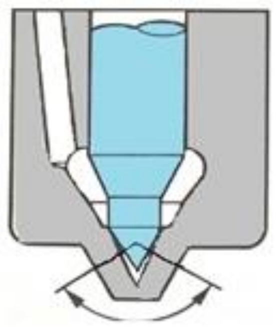
- more economical
- cold starting is easier
- smaller combustion space, better thermal efficiency

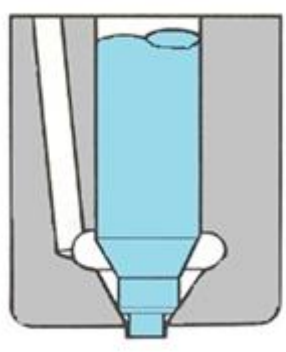
Disadvantages

- more prone to blockages due small injector holes
- require high pressures to atomise the fuel

Progress Check

Identify these injector types. Which type would normally be used in an indirect injection engine?

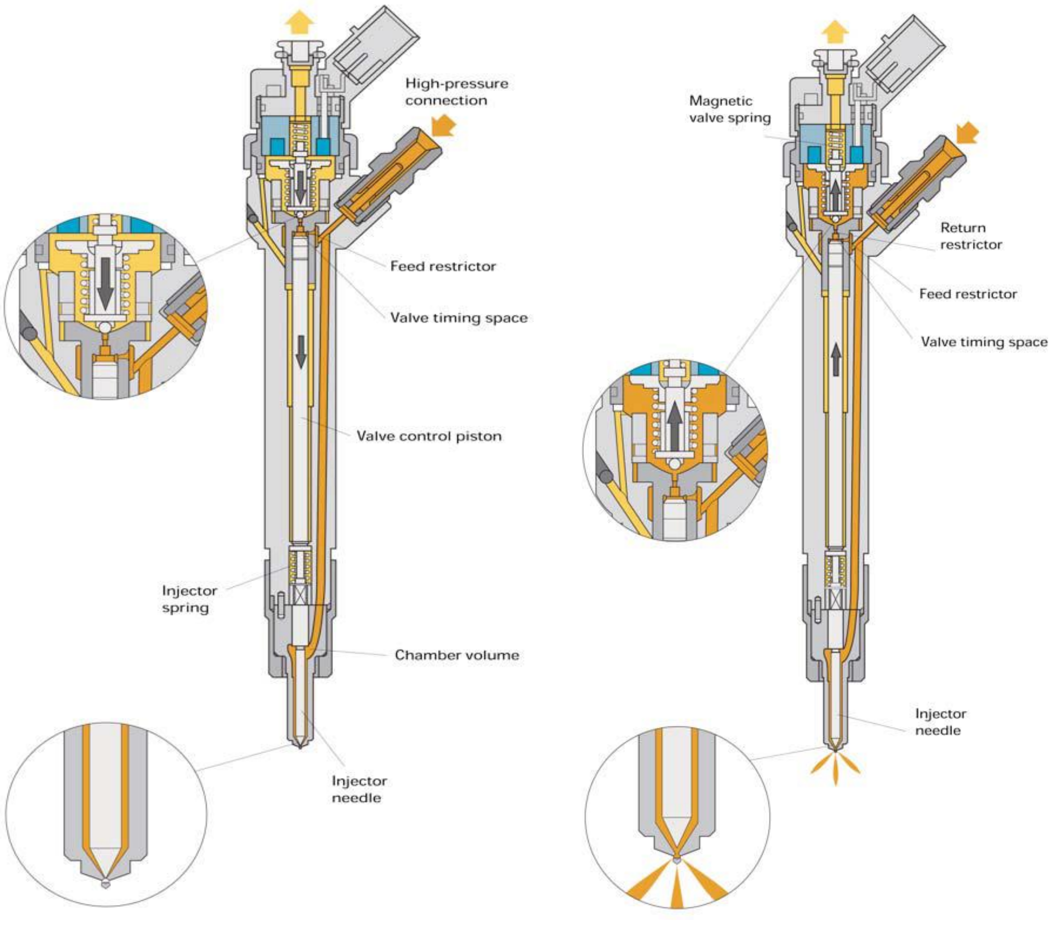




Solenoid Injector

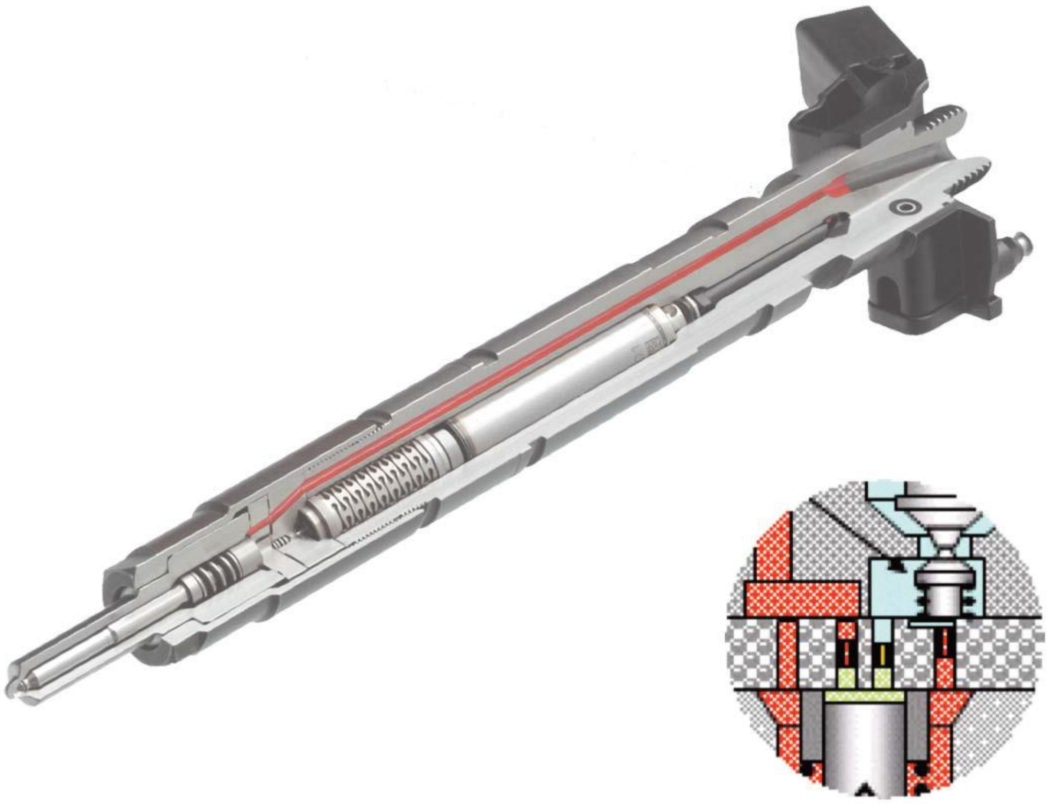
The solenoid valve of the injector is closed
A pressure of 1.5 times the area of the control piston facing towards the injector is generated in order to make sure that the injector is leak-tight. This means that the force exerted by the hydraulic control piston is approx. 50% higher than the nozzle opening force; in addition to the injector spring, the valve control piston presses the injector needle into its seat. The injector spring keeps the injector closed up to a pressure difference of approximately 40 bar between the chamber volume and the valve timing space.

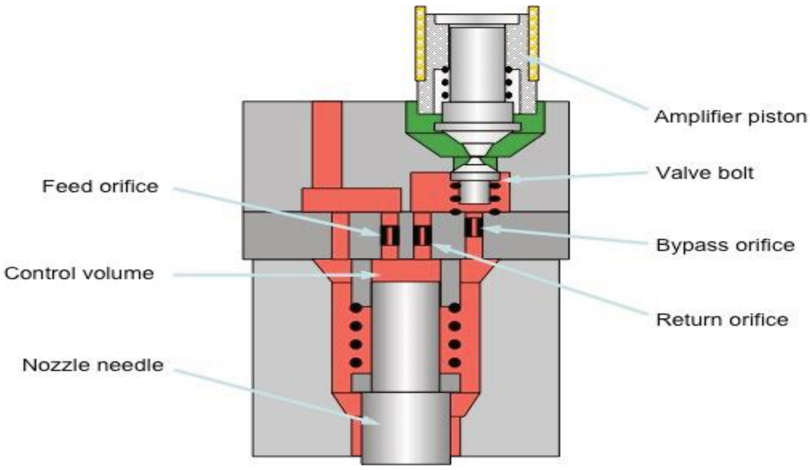
If an electric current is applied to the solenoid valve, the magnetic force will be greater than the closing force of the solenoid valve spring. The solenoid valve opens the return restrictor, relieving the fuel pressure in the valve timing space and reducing the closing force above the nozzle. As a result, the excess fuel and/or rail pressure below the nozzle increases as from an excess pressure of approximately 160 bar on the nozzle side, causing the nozzle to open. The opening velocity of the injector needle is dependent upon the application of a high current for a short time.



Peizo Injector

Peizo injectors use the property of peizo crystals to change shape when a voltage is applied to them. They react much faster than solenoid operated injectors and allow for controlled multiple injections. The piezo crystal acts like a capacitor in that the applied voltage makes the piezo stack expand and stores that energy. The piezo material will not return to its original size until the crystal is short circuited. For this reason, the injector must never be disconnected when the engine is running. Some injectors use an amplifier to increase the movement of the piezo stack. A return pressure is retained to ensure correct filling of the amplifier.



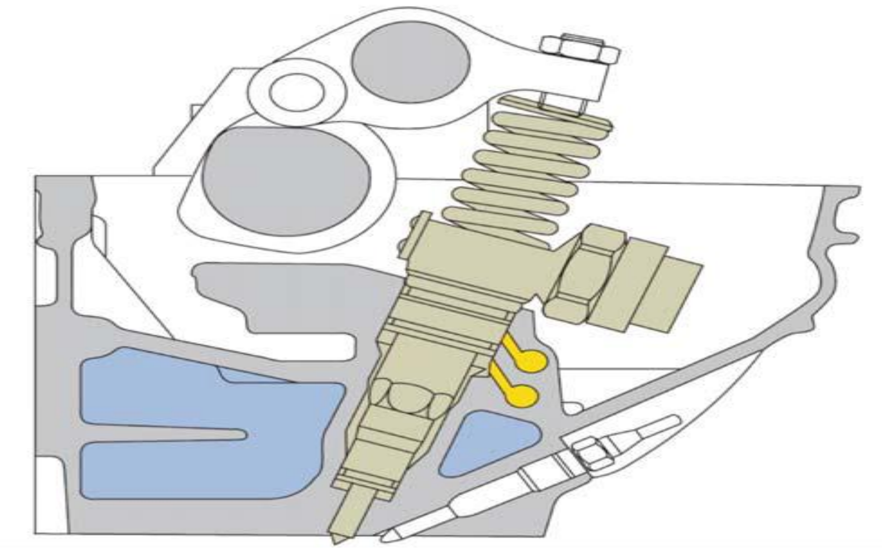


Unit Injector

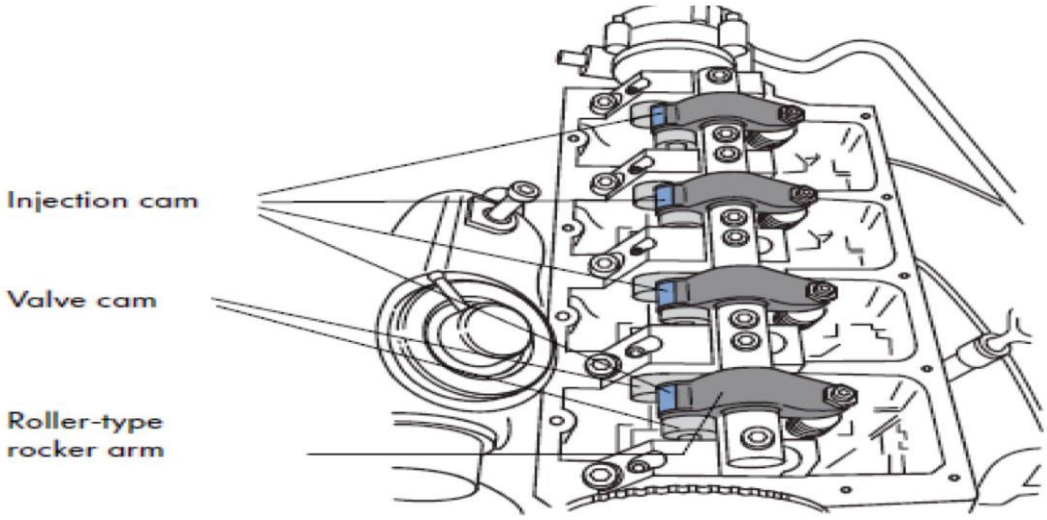
Design and technology
Design of the Unit Injector eliminates the need for high pressure fuel pipes, and with that their associated failures, as well as allowing for much higher injection pressure to occur. The Unit Injection system allows accurate injection timing and amount control as in the common rail system. The Unit Injector is fitted into the engine cylinder head, where the fuel is supplied via integral ducts machined directly into the cylinder head. Each injector has its own pumping element, and in the case of electronic control, a fuel solenoid valve as well. The fuel system is divided into the low pressure (<500 bar) fuel supply system, and the high-pressure injection system (<2000 bar).

Operation principle
The basic operation can be described as a sequence of four separate phases: the filling phase, the spill phase, the injection phase, and the pressure reduction phase. A low-pressure fuel delivery pump supplies filtered diesel fuel into the cylinder head fuel ducts, and into each injector fuel port of constant stroke pump plunger injector, which is overhead camshaft operated.

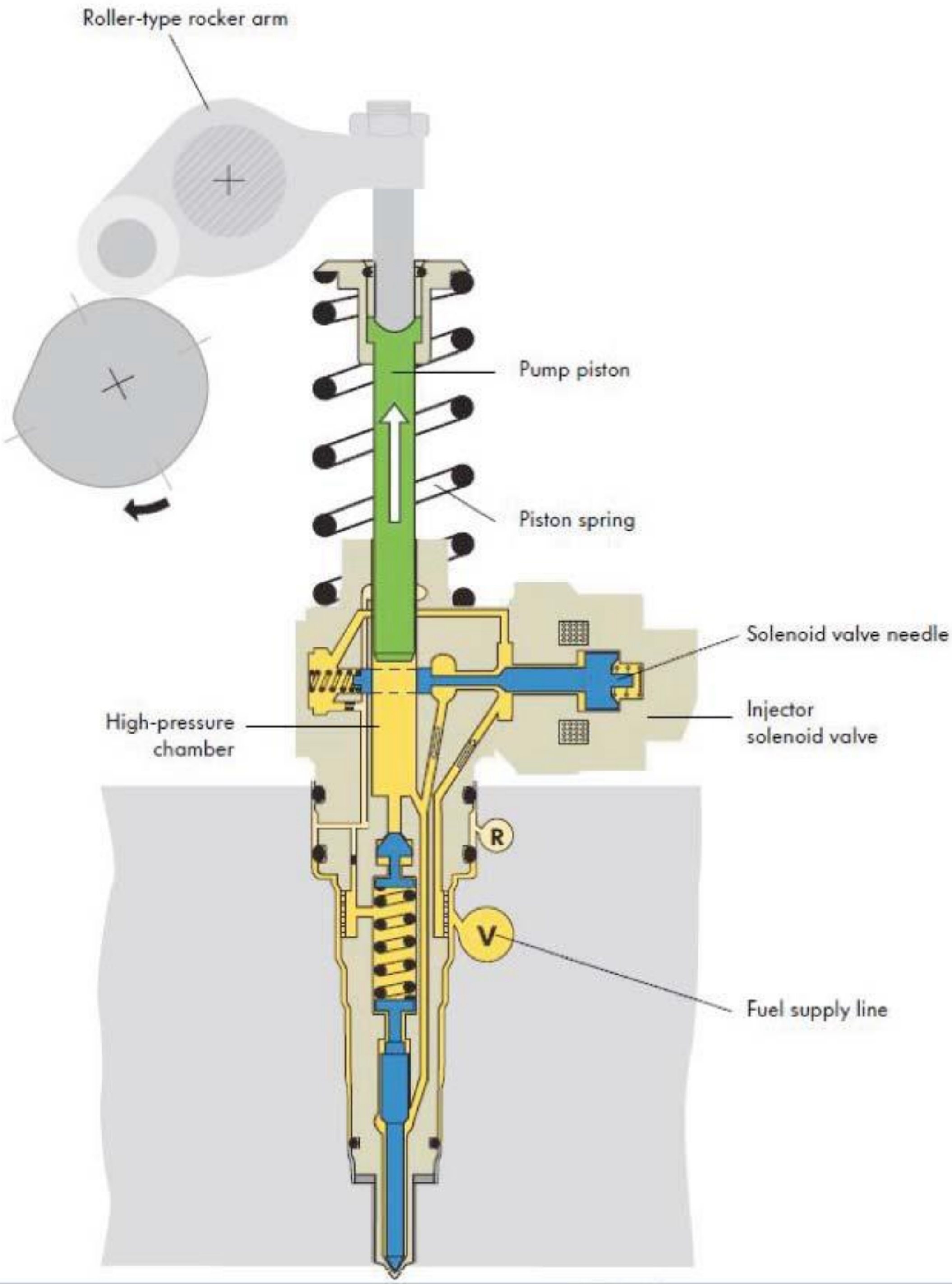
Additional functions
The use of electronic control allows for special functions; such as temperature controlled injection timing, cylinder balancing (smooth idle), switching off individual cylinders under part load for further reduction in emissions and fuel consumption, and multi-pulse injection (more than one injection occurrence during one engine cycle).



Drive mechanism
The injection cam has a steep leading edge and a flat trailing edge. As a result, the pump piston moves up and down slowly and evenly, allowing fuel to flow free of air bubbles into the high-pressure chamber of the pump injector. As a result, the pump piston is pushed down at high velocity and a high injection pressure is attained quickly. The camshaft has four additional cams for driving the pump injector; they activate the pump pistons of the pump injector via roller-type rocker arms.

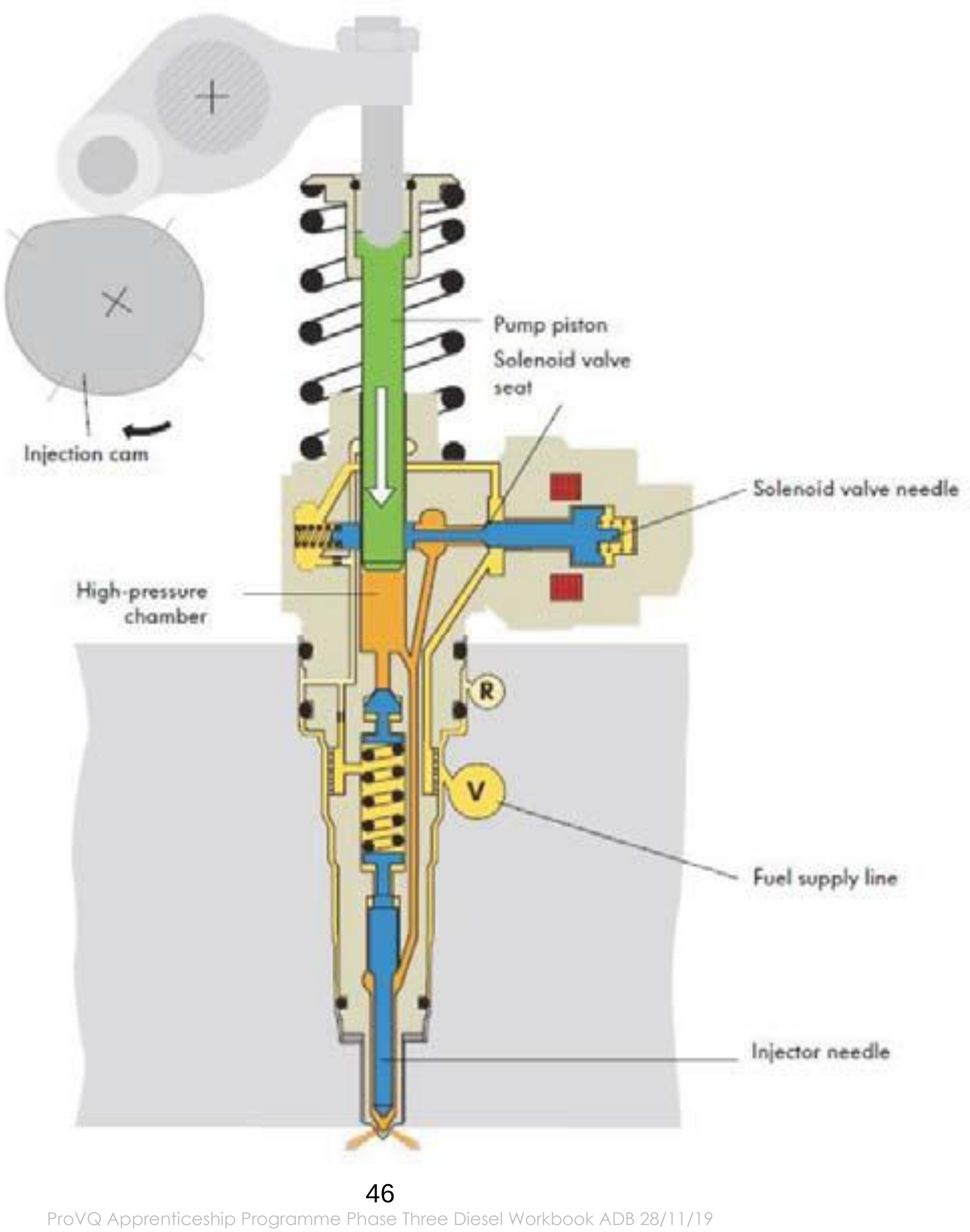


The high-pressure chamber is filled
During the filling cycle, the pump piston moves upwards under the force of the piston spring and thus increases the volume of the high-pressure chamber. The injector solenoid valve is not activated. The solenoid valve needle is in its resting position and opens up the path from the fuel supply line to the high-pressure chamber. The fuel pressure in the supply line causes the fuel to flow into the high-pressure chamber.



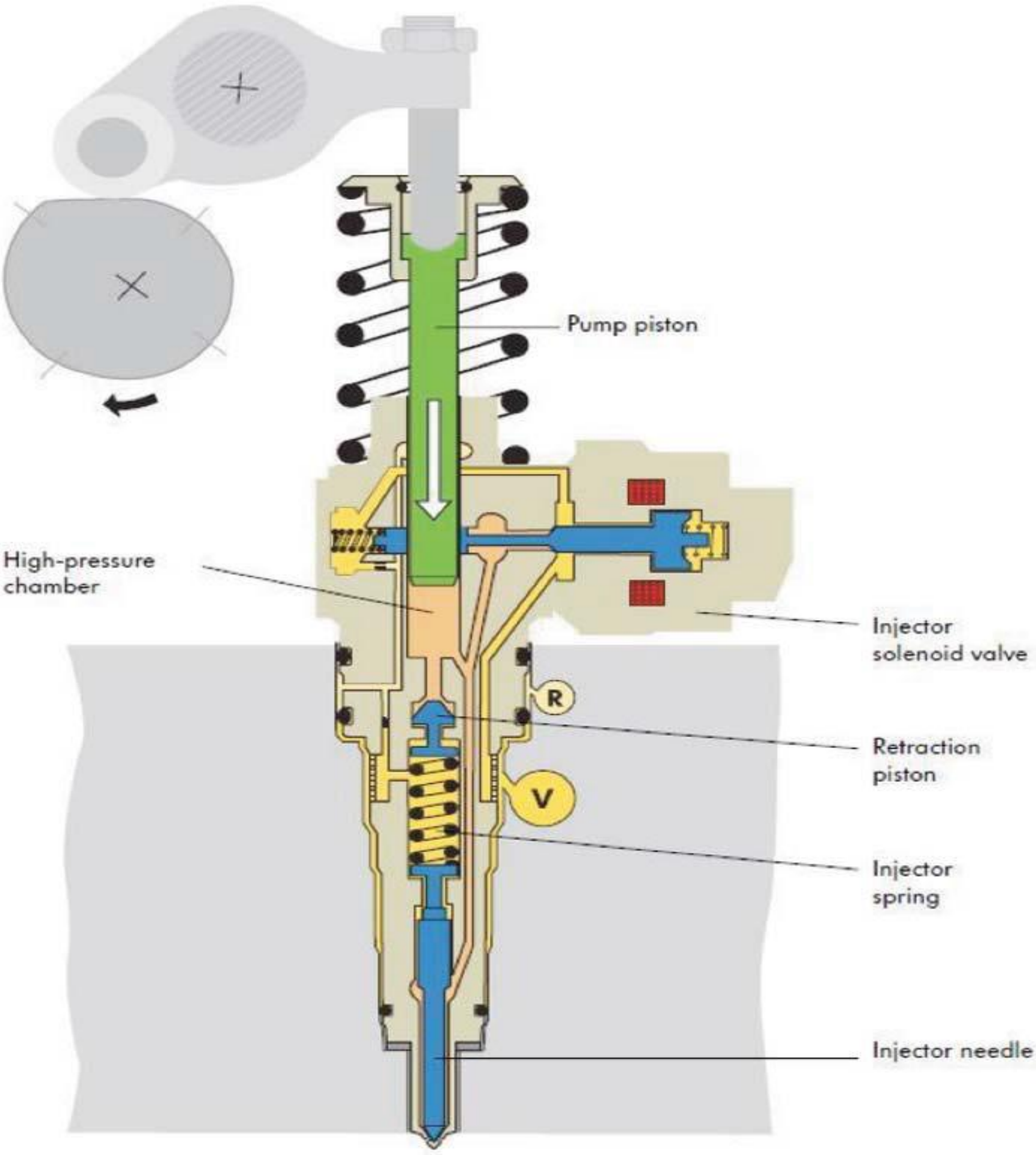
The pre-injection cycle commences

The injection cam pushes the pump piston down via the roller-type rocker arm and thus displaces fuel out of the high-pressure chamber into the fuel supply line. The engine control unit initiates the injection cycle by activating the injector solenoid valve. In the process, the solenoid valve needle is pressed down into the valve seat and closes off the path from the high-pressure chamber to the fuel supply line. This initiates a pressure build-up in the high-pressure chamber. At 180 bar, the pressure is greater than the force of the injector spring. The injector needle is lifted and the pre-injection cycle commences.



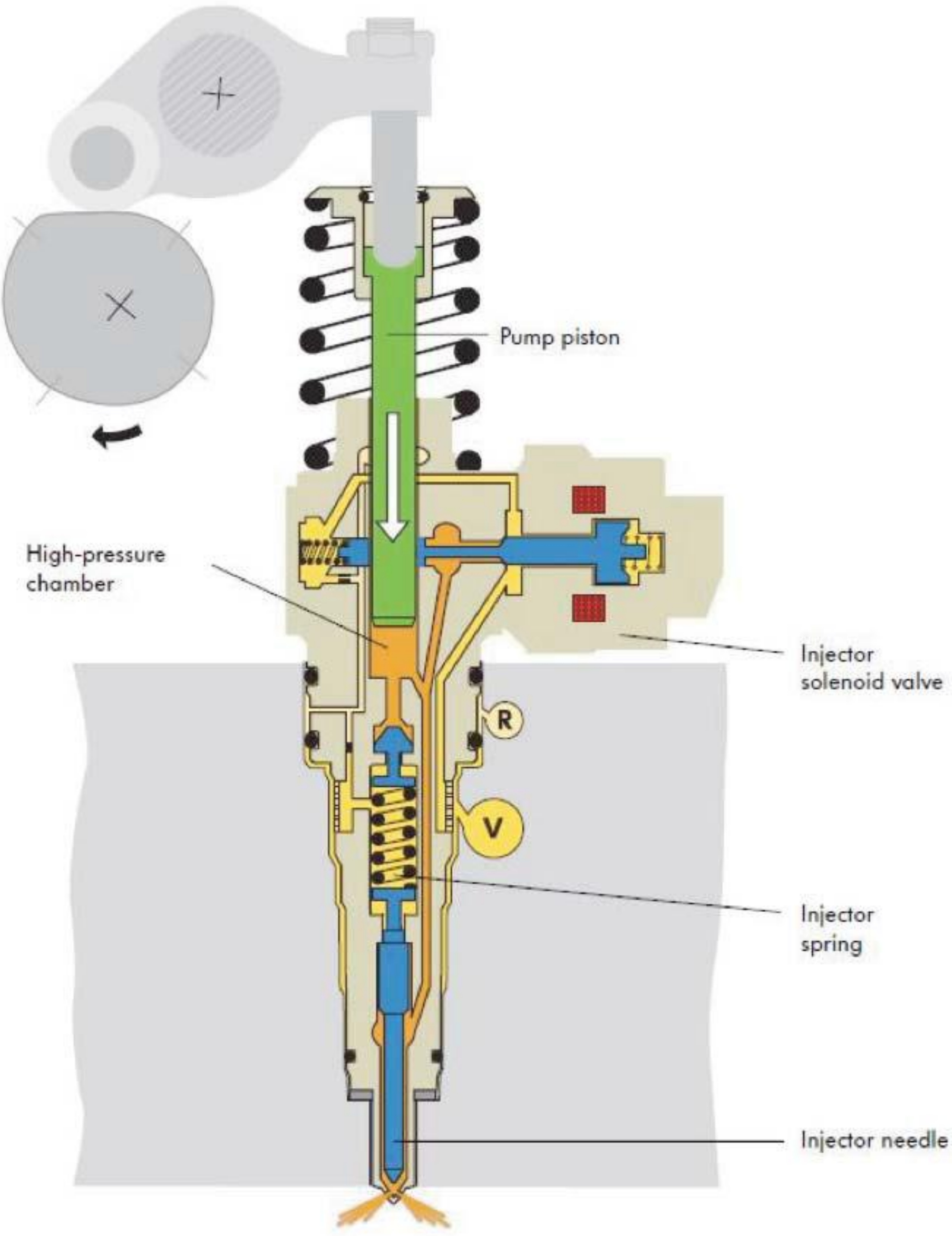
End of pre-injection cycle

The pre-injection cycle ends straight after the injector needle opens. The rising pressure causes the retraction piston to move downwards thus increasing the volume of the high-pressure chamber. The pressure drops momentarily as a result, and the injector needle closes. This pre-injection cycle now ends. The downward movement of the retraction piston pre-loads the injector spring to a greater extent. To re-open the injector needle during the subsequent main injection cycle, therefore, the fuel pressure has to be higher than during the pre-injection cycle.



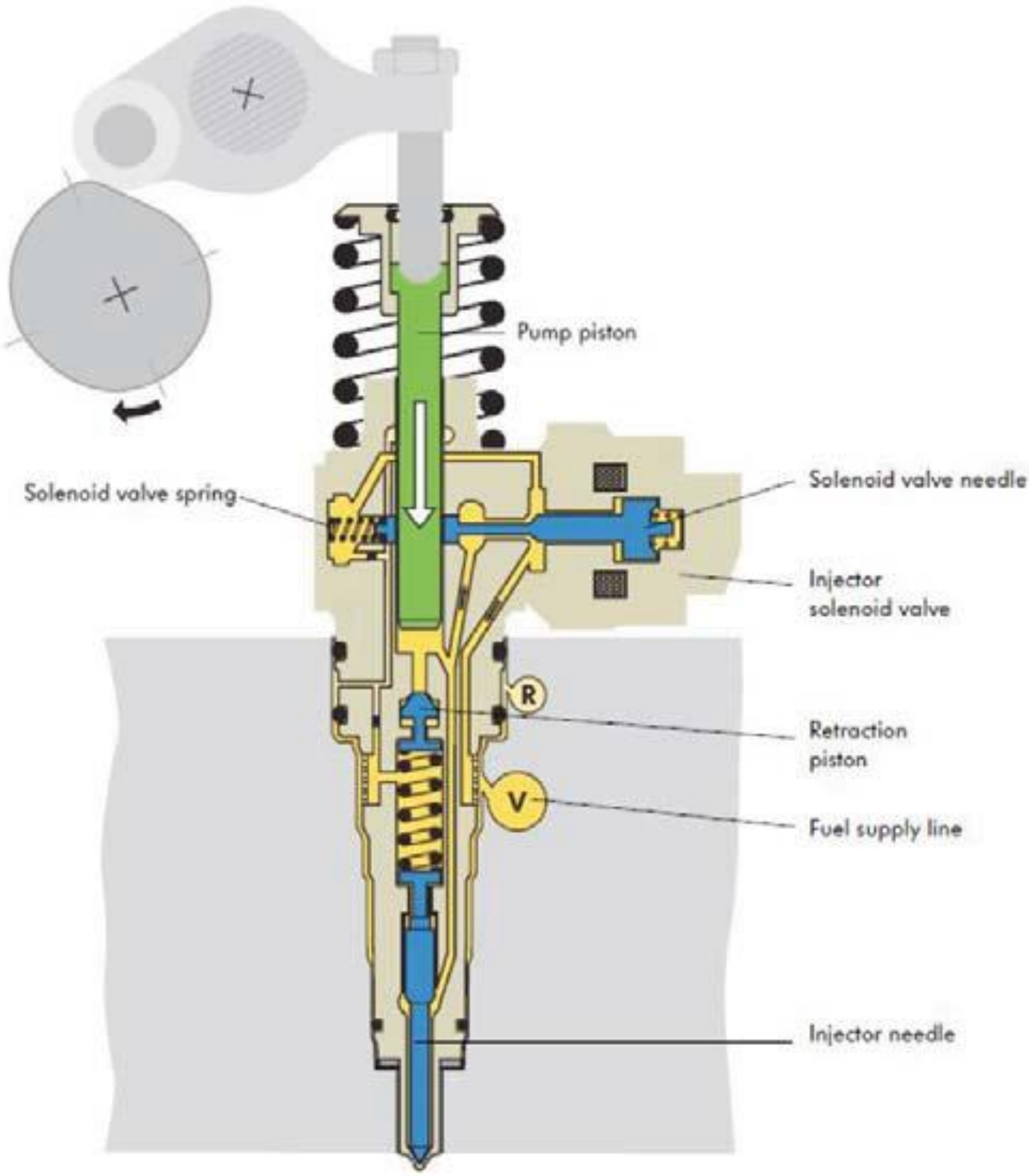
The main injection cycle commences

The pressure in the high-pressure chamber rises again shortly after the injector needle closes. The injector solenoid valve remains closed and the pump piston moves downwards. At approx 300 bar, the fuel pressure is greater than the force exerted by the pre-loaded injector spring. The injector needle is again lifted and the main injection quantity is injected. The pressure rises to 2050 bar, because more fuel is displaced in the high-pressure chamber than can escape through the nozzle holes. Maximum fuel pressure is at maximum engine output, i.e. at a high engine speed with a large quantity of fuel being injected at the same time.



The main injection cycle ends

The injection cycle ends when the engine control unit stops activating the injector solenoid valve. The solenoid valve spring opens the solenoid valve needle, and the fuel displaced by the pump piston can enter the fuel supply line; the pressure drops. The injector needle closes and the injector spring presses the bypass piston into its starting position. The main injection cycle now ends.



Cold Starting Devices

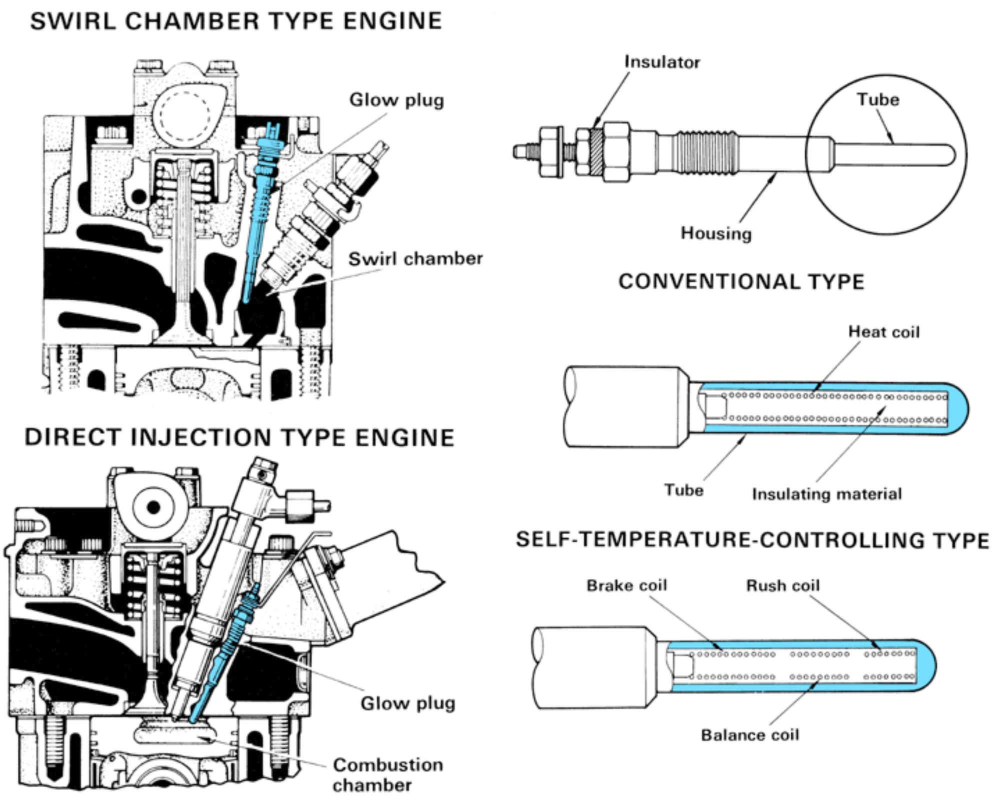
There are inherent problems with starting compression ignition engines during cold conditions. The air temperature on the compression stroke has to be raised higher than the temperature at which diesel will combust spontaneously so starting a cold engine with cold air poses many problems. Although the air temperature in the combustion chamber rises significantly during the compression stroke, there is still a significant amount of heat lost through the cold engine components. The purpose of any cold start device is to either alter the ambient temperature of the air entering the cylinders or to alter its composition and ultimately make it more combustible.

Devices used to aid cold starting include:

- glow plugs
- thermostarts
- flame plugs
- ether.

Glow Plugs

Most diesel engines utilise glow plugs to aid cold starting. Glow plugs are screwed into the wall of the cylinder head, protruding into each combustion chamber. The glow plug housing contains an electrical heating coil inside a tube. The tube is filled with insulating material to prevent the heat coil from touching the inner wall of the tube.



Function

Glow plugs pre-heat the combustion chamber and air within it, before an attempt is made to start the engine. Typically, the ignition is switched on for a few seconds until a timer controlled warning lamp extinguishes. When the engine is cranked by the starter motor, diesel fuel is injected into the pre-heated combustion chamber. The warm air assists the combustion process. In some systems, the glow plugs remain on for some time after starting to aid warm up and reduce emissions.

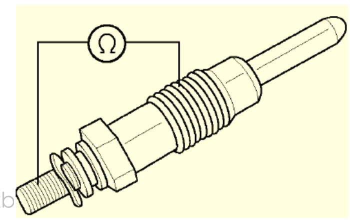
Most systems utilise a glow plug relay assembly to supply power to the glow plugs, which can draw very large currents. The assembly usually contains a relay and timer to supply power to the glow plugs before an attempt is made to start the engine and a separate relay to turn the plugs off during cranking. The second relay prevents excessive current draw during starting by turning the glow plugs off when the starter is operated.

Some glow plugs are capable of varying the current drawn, depending on the cylinder temperature, i.e. when it is very cold they will be on for longer than when it is not so cold. These glow plugs use heater coils which increase their electrical resistance as they get hotter. Therefore, when cold the resistance of the plugs is low and the current flow through them is very high, resulting in the plug heating up very quickly. As they warm up, and the glow plug resistance increases, the current flow is automatically reduced. This type of glow plug is used to speed up the pre-heating phase of starting, without risking overheating the plugs which would reduce their life.

If the glow or heater plugs are faulty then the engine will output excessive particulates during its warm up period which will compromise the DPF system particularly if the vehicle is used for short journeys. Glow plugs are normally controlled by the ECM or can be controlled by a heater plug control module.

The plugs are activated for a period of time according the coolant temperature sensor. They can be tested individually or can be tested as a group using an ammeter. Typical resistance would be 0.6Ω this would mean that on switching them on, each one would draw a current of around 20A. This current drops quickly as the temperature of the glow plug increases (PTC). Some systems will continue to switch the plugs on after the engine has started to reduce diesel knock on warm up. Refer to warm up data for details of the glow plug operation.

The new glow plug system is of the diesel quick start type. In practically all weather conditions, it allows immediate start, like on a petrol engine, without long periods of pre-glowing. In conjunction with 6-hole



injectors, which have a special "ignition" spray pattern, the new glow plug system offers excellent cold starting and cold running properties.

The advantages of the new glow plug system are:

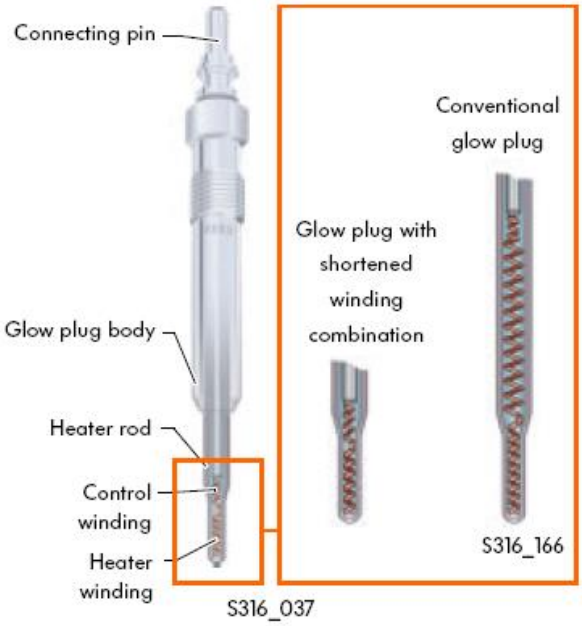
● Safe start procedure at temperatures up to minus 24°C.

● Extremely quick preheating. In a matter of 2 seconds, 1000°C is reached at the glow plug.

● Controllable temperature for pre-glow and extended glow periods.

Glow plug developments

The glow plug consists of glow plug body, heater rod with heater and control windings and connecting pin. The glow plugs have a nominal voltage of 4.4 volts. Compared with conventional self-regulating metal glow plugs, the combination of control and heater windings is reduced by about a third. In this way, it was possible to reduce the glow period down to 2 seconds.



TIP:

The glow plugs should never be checked for operation using 12 volts, as otherwise they will melt.

Pre-glow

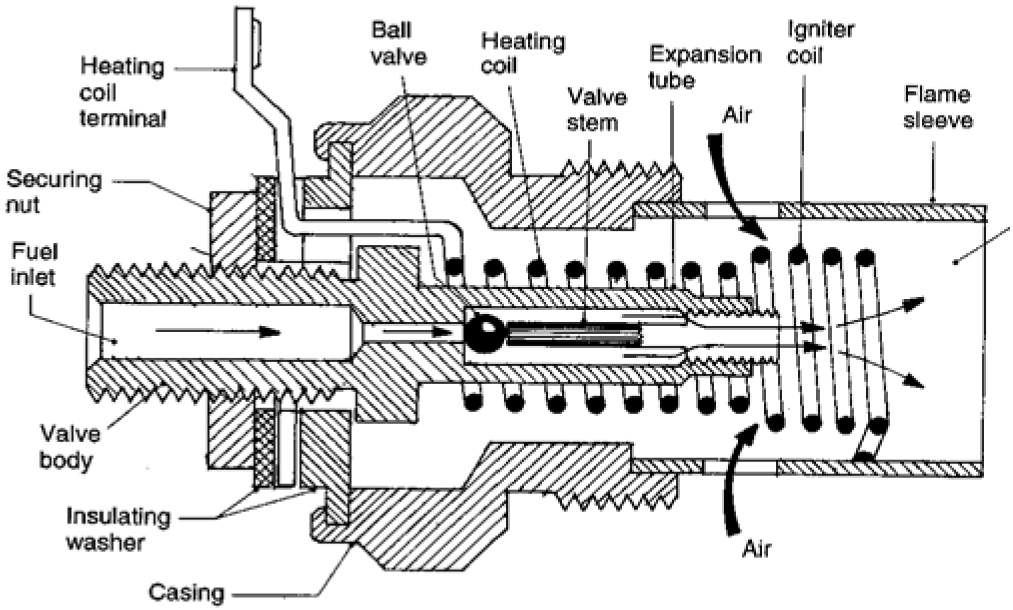
When the ignition is switched on and temperature is below 14°C, the pre-glow system is activated. To do this, the engine control unit sends a PWM signal to the glow plug control unit. The glow plugs will then also be activated by the glow plug control unit by means of a PWM signal.
In the first stage of pre-glowing, the glow plugs are energised for a maximum of 2 seconds with approx 11 volts. Thereafter, the glow plugs are supplied with voltage by the glow plug control unit, depending on the relevant operating conditions.

Extended glow period

Each time the engine is started, an extended glow period is activated to reduce the combustion noise and amount of hydrocarbon emissions. Actuation of the glow plugs is adjusted by the engine control unit depending on engine load and speed.

Thermo-start device

Before glow plugs manufacturers used a device called a thermos-start.



A thermo-start device loosely resembles an injector. It is normally mounted in the inlet manifold, as close to the air intake as possible. The thermo-start device is connected to a small header tank containing a small quantity of diesel fuel; typically, about 25ml. Fuel is initially prevented from entering the casing by a ball valve, held in position by a valve stem with a fluted tip within an expansion tube. A heater coil and igniter coil surrounding the expansion tube are connected to the starter switch and earthed within the valve casing. The tips of the igniter coil and expansion tube are exposed within a perforated flame sleeve positioned directly in the airflow into the inlet manifold.

When the ignition is switched on, current flows through the heating and igniter coils, heating the expansion tube. The valve stem and the expansion tube are made of materials that expand at different rates and the expansion tube increases slightly in length. As a result, the ball valve becomes loose and fuel is allowed to pass over the fluted valve stem and drip onto the igniter coil. When the fuel contacts, the igniter coil it burns, heating the air drawn into the engine during cranking. The heated air/fuel mixture improves cold starting.

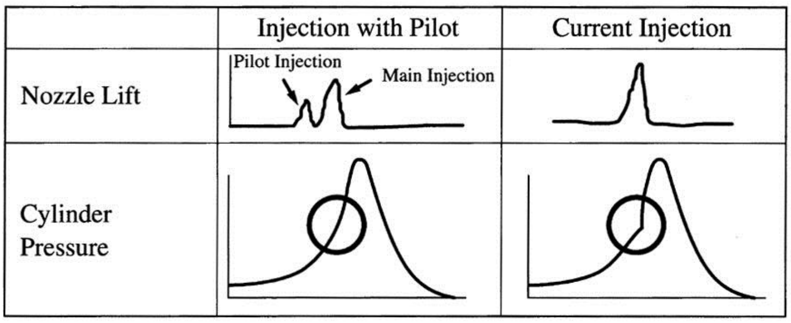
Fuel passing through the expansion tube rapidly cooling the assembly after the starter is released, thereby closing the ball valve.

Combustion

Just like its octane fuelled brother the diesel combustion ingredients are identical. Air (78% nitrogen, 21% oxygen and 1% other) and fuel, a refined blend of hydrogen and carbon 16 and 85% respectively. It is the way they are introduced and the different characteristics the larger fuel molecules have that sets them so far apart.
Diesels have gone through some pretty drastic changes in recent years as emission laws have become increasingly stringent. As a result we now see the common rail system as the industry standard due to its optimised efficiency and emission control. The common rail system injects fuel in stages at a very high pressure (approx 1500 Bar) into the cylinder.
The combustion process is broken down into various stages (up to 7) but consists of 2 main stages:

Pilot injection

The pilot injection has the job of reducing the dreaded knock caused by the delay between the injection of fuel and the ignition of the fuel. It does this by injecting a small amount of fuel into the compressed air before top dead centre (TDC). This small amount of fuel ignites causing an initial pressure rise. Released heat overcomes the problem of the knock associated with diesel. The initial heat reduces the quenching effect as the cylinder walls absorb some of the initial heat released. Pilot will only operate up to around 3000 rpm.



Main injection

As the piston nears TDC and pilot injection has occurred the ECU now initiates injection into an already burning ball of flames. This provides the rapid smooth rise in pressure and allows torque control via the amount of fuel injected. This method of injection maximises the efficiency by burning all the fuel evenly thus minimising emission output.

Emissions

The emissions emitted from diesel combustion are almost identical to those of a petrol engine being:

Carbon monoxide

Carbon monoxide is the by-product of incomplete mixing of the carbon and oxygen. With direct injection, the epicentre of combustion occurs at the centre point of the injector. This causes the flame to spread from the centre outwards causing poor mixing at the further most point.

Unburnt fuel is usually the result of poor atomisation and penetration. The bigger the droplet the lower its velocity if the fuel is clumped together the fuel on the outside gets the oxygen and forms a barrier between the fuel in the centre and the available oxygen. Poor air movement and bad injectors are the biggest culprits

Carbon dioxide

As we may remember carbon dioxide is the desired result of combustion resulting from the carbon mixing with oxygen correctly.

Hydrocarbons

Raw un-burnt fuel exiting through the exhaust is always going to be an undesirable emission. It can come from poor mixing of the air and fuel and the time it takes for the flame to spread.

Particulate matter

Also, known as ‘soot’. This emission is one most of us have all seen and felt the effects of at some point. Soot is caused by carbon being left on its own without any oxygen. This causes it to become baked during the large temperature increase and then be pushed out into the exhaust then into the atmosphere.

Specific heat capacity (SHC) describes the amount of heat energy it takes to raise the temperature of a substance. Air has an SHC of around 1kJ/kg/ ℃ whereas steam has an SHC of 2.25kJ/kg / ℃

Oxides of nitrogen (NOx)

Diesel engines are not “strangled “like a petrol engine. They take in a cylinder full or more with every stroke. The engine torque is controlled by the amount of fuel injected. The air fuel ratio varies from 17:1 and 29:1 under load and 50:1 to 145:1 at idle or no load. This means that a diesel engine only ever runs weak (unless there is a fault) and only runs close to stoichiometric at full throttle and load. Unfortunately, very high localised temperatures within the combustion chamber lead to the production of NOx. There are a number of strategies to control NOx emissions and the most common is exhaust gas recirculation. Exhaust gas is a mixture of CO2, H2O, Nitrogen, and some oxygen. The effect of this is twofold. Firstly, the CO2 and H2O thin out the oxygen and slow the rate of combustion. Secondly the H2O has a high specific heat capacity. Both cause a reduction in peak temperatures and so reduce NOX production.

Exhaust gas recirculation (EGR)

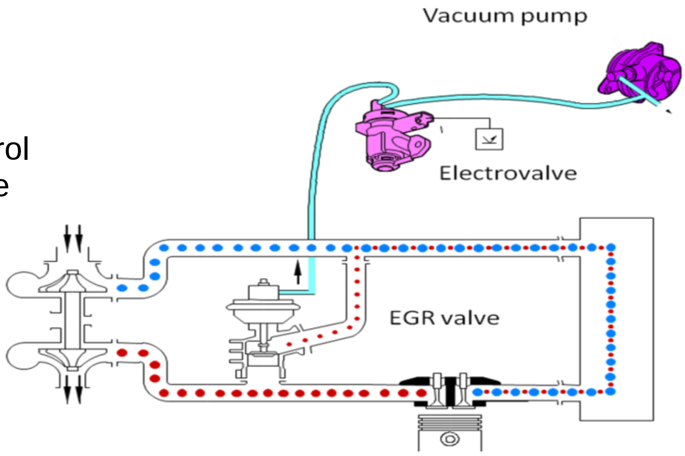
Diesel engines take in a full cylinder of air with every stroke. The engine speed is controlled by the amount of fuel injected. This means that a diesel engine only runs rich at or near full throttle. A weak mixture generates very high localised internal temperature within the combustion chamber which in turn leads to the production of NOx. In order to reduce the production of NOx it is necessary to reduce the amount of nitrogen entering the engine. The only way to do this is to reduce the amount of air coming into the engine so that the fuel to air ratio is closer to the correct fuel/air ratio. In order to do this, diesel engines rely heavily on their EGR system.

The differences between petrol and diesel

Diesel has a distinct difference to petrol in relation to manifold pressure. Diesel engines use throttle pedal angle as a demand for increasing or reducing fuelling. This means that the pressure drop associated with conventional throttles is not used for restricting air flow. Instead the engine

ECU controls the amount of throttle opening for alternative gains. These benefits come in the form of reducing noise during idling and deceleration as well as noise and vibration that are generated when the engine is stopped. During EGR operation the throttle valve moves towards the closed direction to increase manifold vacuum. This in turn means a greater amount of EGR can be introduced.

EGR operation



While the modern diesel has now been refined to be at its most efficient, the down sides are still oxides of nitrogen (NOx). The control of such emissions has now become very advanced in the strategy used to reduce NOx emissions to a minimum. Ultimately exhaust gas recirculation systems (EGR) have become very complex in their operation due to the different operating strategies used.
Just like the petrol the same goal exists of cooling the exhaust gas once it has left the cylinder. The recirculated exhaust gas will then absorb some of the heat produced during combustion by increasing the heat capacity of the mixture in the cylinder.

EGR can be controlled by various methods such as a control solenoid or an electro valve operation. The solenoid can powered by the ECU to open dependent on engine load. The electro valve operation uses the brake servo pump to actuate the pressure differential at the EGR diaphragm.
Whereas petrol engines use EGR at light load and high engine speed, diesel engines use their EGR systems throughout their rev range and can be up and can provide 60% of the total intake at idle! It also helps during initial warm up to increase cylinder temperature reducing noise significantly. Because of the constant use and the harsh conditions EGR coolers are commonly used. This involves the exhaust gas travelling through a heat exchanger depending on operating conditions such as warm up or full throttle.
This ensures sufficient cooling of the recirculated gas before entry back into the cylinder. Some coolers feature an oxidation catalyst to minimise clogging in the cooling fins caused by HC and particulate matter.

EGR feedback

Due to the amount of EGR that is introduced in diesel operation the engine management system requires some form of feedback to monitor operation. This can be measured in various ways. Measurements of manifold pressure and air flow on some systems are enough to calculate EGR. Whereas some systems use actual EGR valve opening that is measured via the actuator solenoid to provide the engine management ECU with a real-time value.

Oxygen sensors

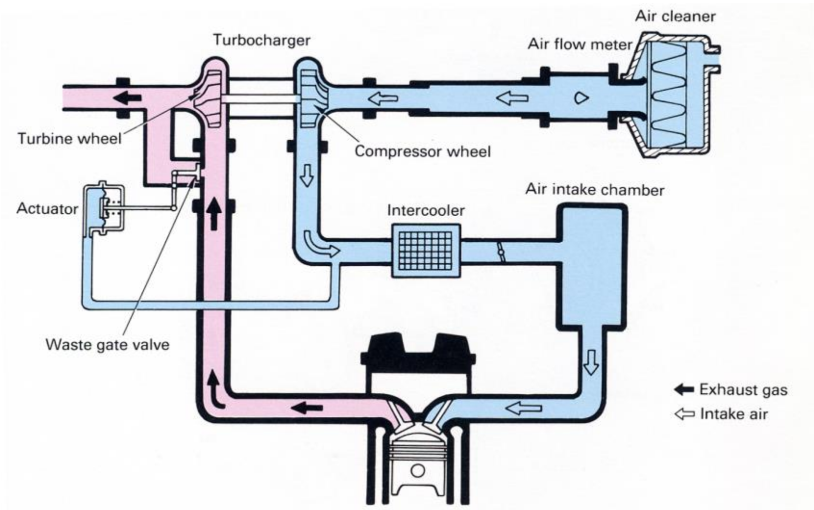
Becoming ever popular is the use of a wide or broad band oxygen sensor. These sensors are currently the most accurate way to monitor oxygen content in the exhaust gas. This data can then be used in a similar way to that of a petrol engine management system as a closed loop control to monitor and control EGR actuation against the preprogrammed map value in the ECU. If the sensor detects a too lean situation, EGR is increased causing the mixture to enrich. When the sensor detects a rich mixture, EGR is reduced causing a leaner mixture.

The values detected are also used in conjunction with corrective injection duration. This has a significant difference to the overall drivability and the emission output of the modern diesel vehicle.
In addition to the EGR control other factors such as particulate filters and NOx reducing catalysts are used to further reduce emissions.

Turbo chargers

Today, the turbo charging of petrol engines is no longer primarily seen from the performance perspective, but is rather viewed as a means of reducing fuel consumption and, consequently, environmental pollution on account of lower carbon dioxide (CO_2) emissions. Currently, the primary reason for turbo charging is the use of the exhaust gas energy to reduce fuel consumption and emissions.

Description

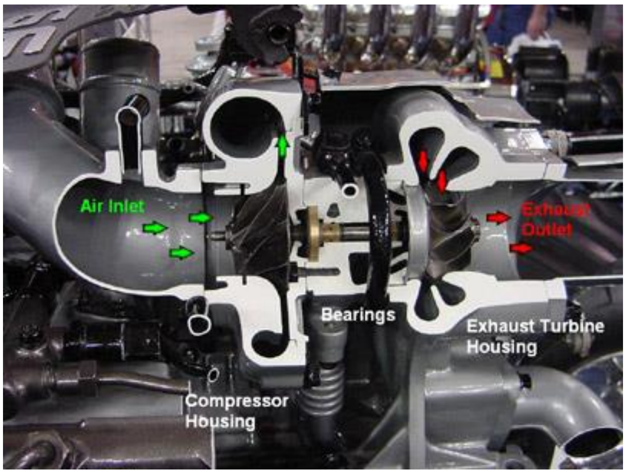


The turbocharger is basically an air pump that is designed to utilize some of the fuels energy that would otherwise be wasted in the form of exhaust gases. These exhaust gases drive the turbine wheel, which is connected to the compressor wheel by the means of a shaft. This compressor wheel is driven at high speeds, forcing the air into the cylinders. Since turbochargers use the wasted energy of the exhaust gases, the power output of the engine can be increased with less power loss.

Turbochargers are used in both Diesel and Petrol engines. Early turbochargers were provided with a waste gate and later designs with a variable nozzle to control boost the boost pressure of the intake air. Most turbocharged engines today are equipped with an intercooler to lower the intake air temperature. This prevents engine knocking and improves air intake efficiency.

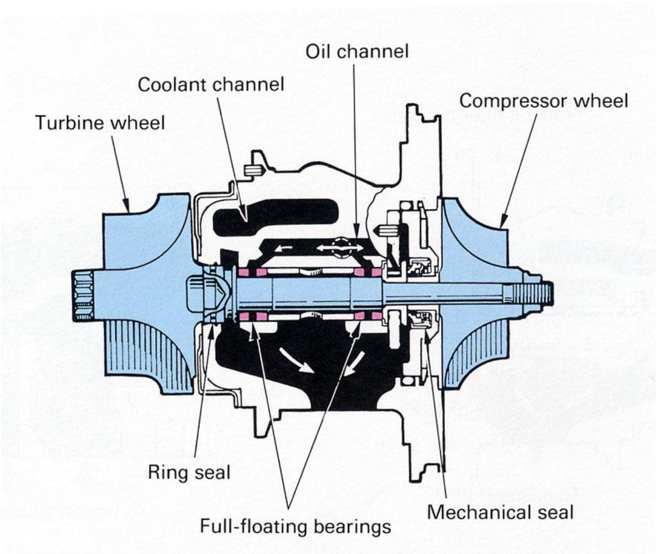
Turbine & Compressor Wheels

The turbine wheel and the compressor wheel are mounted on the same shaft. Exhaust gas flows from the exhaust manifold to the turbine wheel, and the pressure of the exhaust gas turns the turbine wheel. When the turbine wheel turns, the compressor wheel also turns. Air is drawn in and is compressed as the blades spin at a high velocity. The compressor housing is designed to convert the high velocity, low pressure air stream, into a high pressure low velocity air stream, forcing the air into the cylinders. Since the turbine wheel is exposed directly to the exhaust gases, it becomes extremely hot; and since it rotates at high speed it must be heat resistant and durable.



Centre Housing

The centre housing supports the turbine and compressor wheels via the shaft. Inside the housing, engine oil is circulated through channels that are provided for this purpose. Engine coolant is also circulated through channels that are built into the housing.

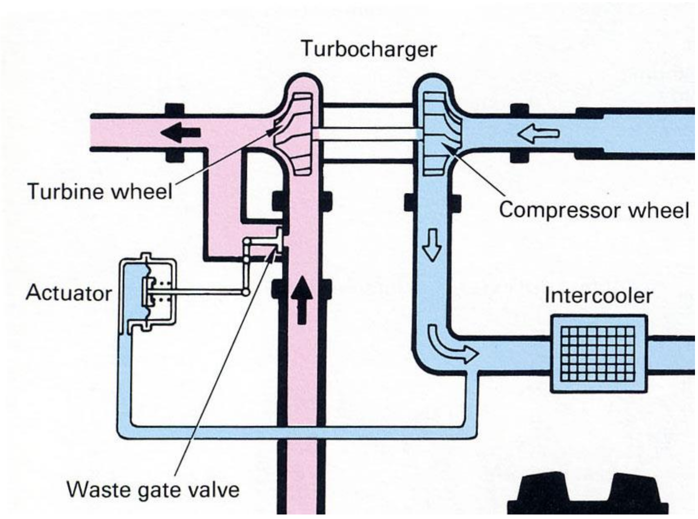


Since the turbine and the compressor wheels turn at speeds of up to 170,000 rpm, fully floating bearings are used to ensure the absorption of vibrations from the shaft and lubrication of the shaft and bearings. These bearings are lubricated by the engine oil and rotate freely between the shaft and the housing to prevent seizing during high speed operation. Engine oil is prevented from leaking by two ring and a mechanical ring seals fitted to the shaft.

Turbo-Lag

When the engine is over-running the exhaust gas flow is reduced, this has the effect of reducing the turbo shaft speed. When demand is suddenly increased boost pressure is low and there is a delay in the production of engine torque. We call this turbo lag. Designers have sought to reduce this effect. The most common method is to use a small turbo which reacts more responsively due to reduced inertia and high turbine speeds from lower gas flow. The downside is that a small turbo acts as a restriction in the exhaust passage at high speed and load when exhaust gas flow is greatest. To overcome this a bypass for the exhaust is required.

Waste gate & Actuator



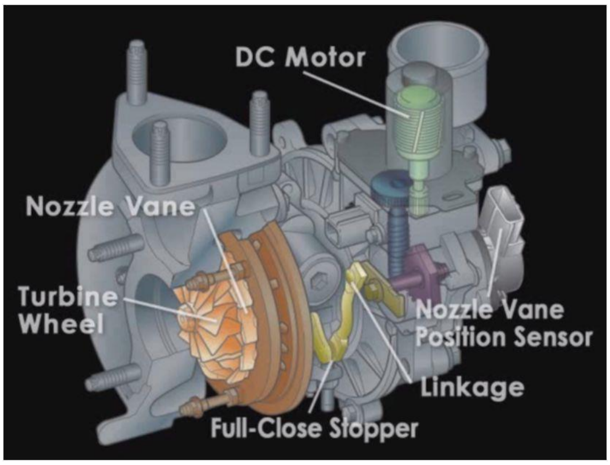
A waste gate valve is built into the turbine housing. Its purpose is to reduce the boost pressure when this begins to rise too high. When this valve opens, part of the exhaust gas by-passes the turbine wheel and flow into the exhaust pipe. The opening and closing of the waste gate valve is controlled by the actuator which can be vacuum or electrically operated.

Intercooler

As intake air is compressed by the turbocharger, its temperature increases. Cooling the intake air raises the air density, improving intake efficiency thus ensuring high power output. At the same time, by lowering the temperature of the air fuel mixture, knocking is suppressed, giving improved driveability and fuel economy. The intercooler may be installed at various locations depending on the vehicle design.

Variable Geometry Turbo

Exhaust Gas Recirculation (EGR) used to control the production of oxides of nitrogen plays an important part in meeting emissions regulations. For EGR to work the exhaust gas pressure must be higher than inlet manifold pressure and whilst waste gate control can achieve this it falls down in the transition between different throttle openings. Excessive EGR will cause black smoke in diesel engines. In vehicles fitted with particulate filters this can cause problems. For the whole system to work seamlessly, the control of boost pressure and EGR has to very accurate. This is where the variable geometry turbo comes in. The exhaust gas from the exhaust manifold passes through nozzle vanes before reaching the turbine.



The angle of these vanes can be altered. When the angle is shallow shown right the restriction created increases the gas velocity and the angle of impingement of the gas on the turbine passes more of its energy to the turbine. This is used when engine speed is low and load is high. Turbo lag is reduced.

As engine speed increases or as load demand decreases, the nozzle angle is steepened. This reduces the energy passed from the gas to the turbine and reduces the back pressure in the exhaust manifold. The angle of the nozzles is infinitely variable between these two extremes. Control of the VGT is programmed into the ECU software.

Diesel engine management

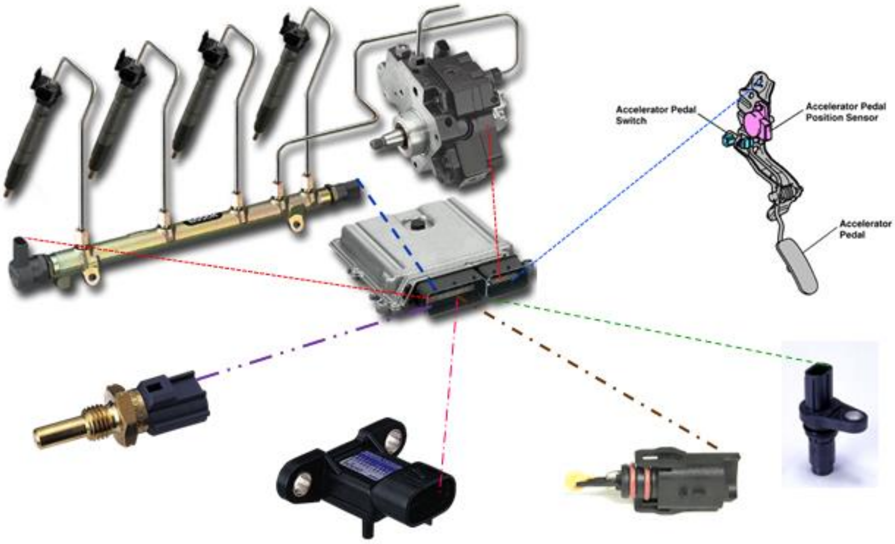
Electronic control systems consist of sensors (information gatherers), an ECU (Electronic Control Unit – the decision maker) and actuators (to carry out actions). It is a three-way process – the sensors gather the information and the ECU receives this information. The ECU processes the information and makes a decision based on what it has been taught. That decision is translated into an action by an actuator and something happens based on that action.

Electronic control systems are based on what is probably the most adaptable, intelligent thing on the face of the planet. Us!

Think about how we interact with the environment – we sense something (sight, sound, smell, taste, touch) using our sensors (eyes, ears, nose, tongue, nerve endings) and the information that we sense is sent to our brain (ECU) for processing. Our brain (ECU) makes a decision based on that information and controls our actuators to suit the situation (our muscles).

We pick something up, sense that it's too hot to touch, and drop it.

It should be noted that we are discussing the fundamentals of electronic control here. This same basic principle can be applied to any electronic control system – EFI, ABS, cruise control etc.



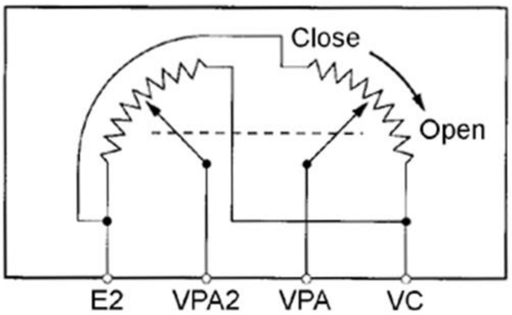
A fully integrated engine management system controls the fuel injection system. Such integration allows the fuel injection programmes to provide optimum control. The result is a reduction in emissions and an improvement in performance whilst maintaining fuel economy.

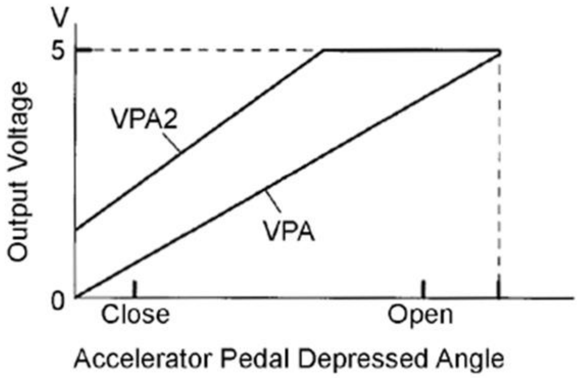
The electronic control unit (ECU)

The electronic control unit is often referred to by many names e.g. DME (digital motor electronics) or PCM (power control module). They all carry out the same role as the brain of the system and effectively make the decisions. In reality an ECU can only make decisions based on the information received from sensors and then performs a task based on the pre-programmed information. The ECU is limited in its decision-making process as it can only make decisions based on the programming it has been given.

Throttle pedal position sensor

The ECU needs to know the position of the throttle pedal for one overriding reason – injection duration. Unlike the petrol engine, when the driver presses hard on the accelerator pedal a larger amount of fuel is required to be injected in order to incease the power out put. The throttle pedal is used to supply the ECU with the main signal to calculate injection duration. In some cases an idle speed switch is intergrated to allow the ECU to recognise idle speed requirements.





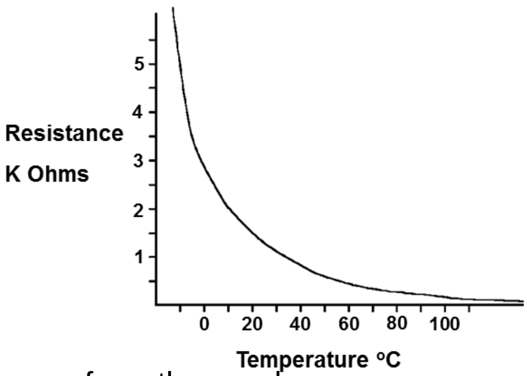
The diagram above shows the principle behind the throttle position sensor. The ECU applies 5v to the resistor track. The moving contact (in blue) effectively divides the resistor track into two resistors wired in series with one another. As the moving contact moves (it's connected to the throttle linkage) it will adopt a position that dictates the comparative length of the two resistors. If they are the same length, then the voltage will be half supply (2.5v) in the middle where the moving contact is. The moving contact is connected to the ECU via the harness and the ECU senses 2.5v. This it interprets as 50% throttle opening. All voltages sensed in between fully closed and fully open represent a known throttle angle to the ECU. This type of sensor is often referred to as a 'potentiometer'.

Why sense temperature?

An engine's temperature must be sensed due to the differing fuelling characteristics required of engines at different temperatures. This is because fuel tends to condense onto the inside of cylinder walls when the engine is cold. Therefore, the amount of fuel that ignites in the cylinders is reduced.

The temperature of the air induced into the engine must also be sensed by the ECU as the density of the air will vary in accordance with this (very cold air is considerably more dense than hot air and therefore the cylinders are receiving more oxygen per intake stroke).

Temperature sensors

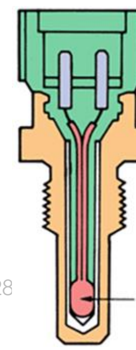


A material that experiences a change in resistance in proportion to a change in temperature acting upon it is referred to as a thermistor (thermal resistor). There are two categories of thermistor-NTC (negative temperature coefficient) and PTC (positive temperature coefficient). Silicon is a good example of an NTC thermistor, and most metals are PTC. How an NTC thermistor behaves can be seen from the graph opposite.

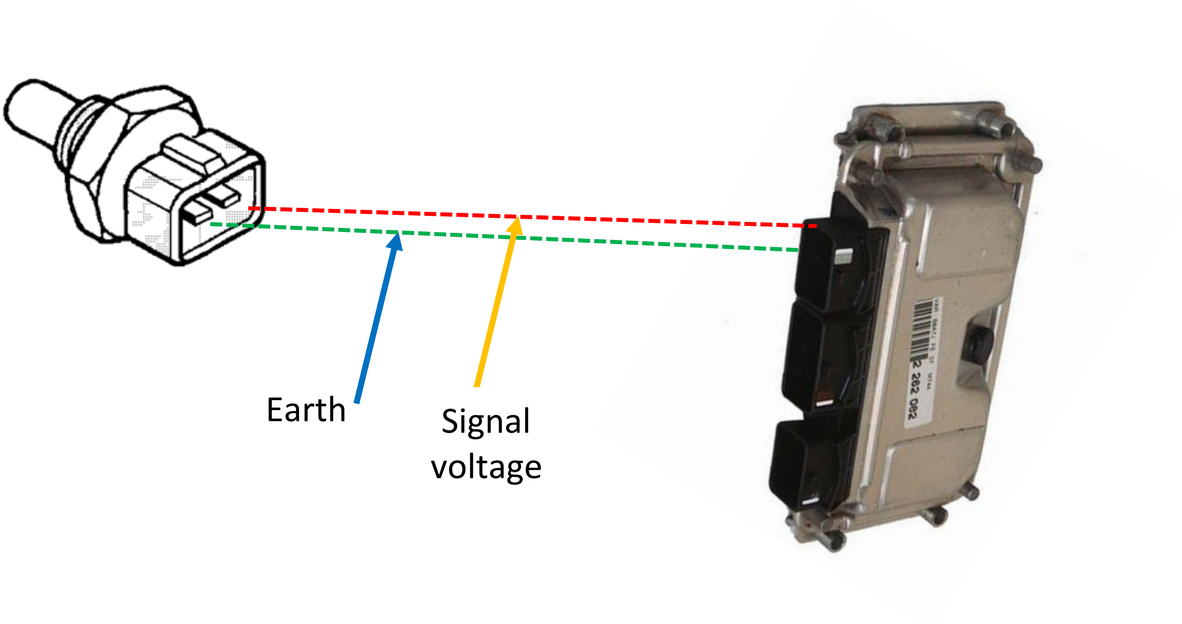
NTC = Sensor resistance decreases as the temperature increases

PTC = Sensor resistance increases as the temperature increases

NTC thermistors are commonly used to sense temperature, as they tend to experience a very large resistance change for a relatively small temperature change. This leads to greater accuracy.

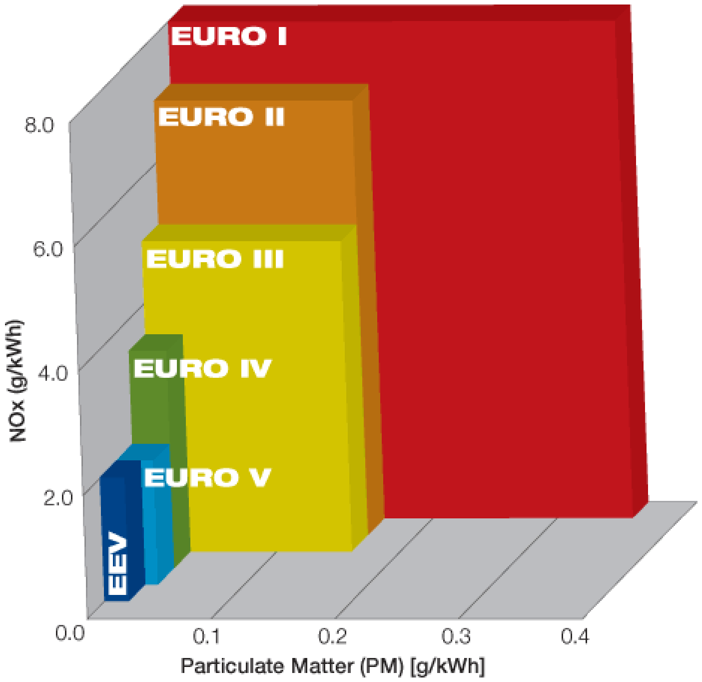


The ECU applies 5 volts to the series circuit which consists of a fixed resistance (inside the ECU) and a variable resistance-our thermistor. If the engine temperature is low, the resistance of the sensor will be high (NTC) and therefore the sensor will have greater resistance influence on the circuit comparatively (that is compared to the fixed resistance). The voltage in between the two resistors will therefore be high. The ECU monitors the voltage at this point and compares its value to programmed temperature equivalents mapped to its memory. A high voltage means a cold engine and the injection duration will be long to compensate. As the temperature of the engine increases, the resistance of the sensor will reduce (NTC) and the fixed resistance will now have a greater effect on the voltage. The voltage in between the two resistors will now be lower. This is interpreted by the ECU as a higher engine temperature and the fuel injection duration will be reduced.



Diesel particulate filters DPF

The modern diesel is a much more sophisticated affair than its 1980's predecessor and the impetus for much of the technology that has given us smooth, powerful, clean diesels in our cars today has come from emissions regulations. It is unfortunate that in order to meet these increasingly stringent regulations, diesel engine manufacturers have had to turn away from improving the combustion process to using treatment of the exhaust.



NOx or particulates?

As can be seen on the chart it is the reduction of oxides of nitrogen and particulate matter PM (soot) that has become the battle ground for the manufacturers. NOx is formed when the combustion temperatures exceed 1800℃. The oxide formed depends not only on the temperature but the length of time the heat is applied. Most manufacturers have used Exhaust Gas Recirculation (EGR) as a method of reducing NOx formation. This works by re-introducing the relatively inert exhaust gasses as a percentage of the total intake, which has the effect of slowing down the combustion process and reducing the peak temperatures in the combustion chamber. Unfortunately, it has side effects, as detailed below

Reduced Thermal Efficiency

A longer combustion means the heat energy has more time to pass into the cooling system, which means that a more effective cooling system has to be used. The injection timing also has to be advanced to account for the prolonged combustion, causing some loss of mean torque and thermal efficiency; consequently, fuel consumption increases.

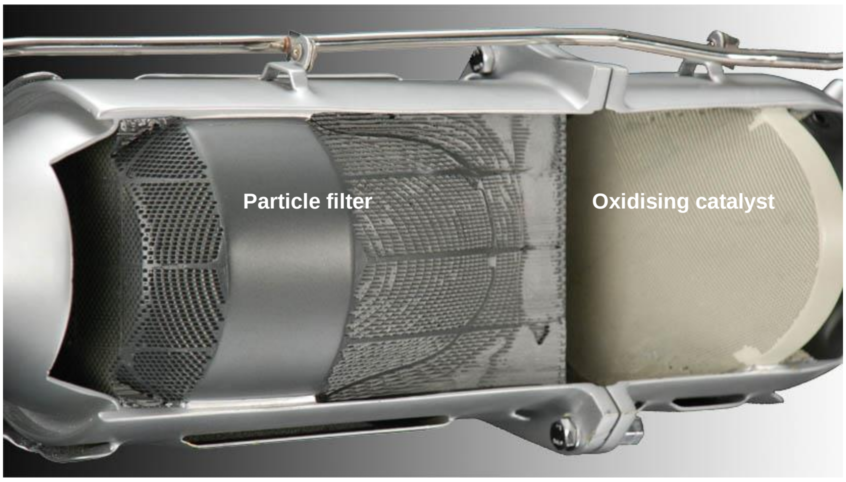
Oxides of nitrogen are pollutants. NO_2 is a toxic reddish brown gas which has a biting pungent odour.

Inhaling particulate matter can cause asthma, lung cancer and heart problems. Particulate matter (PM) contributes to global warming

Increased Soot Output

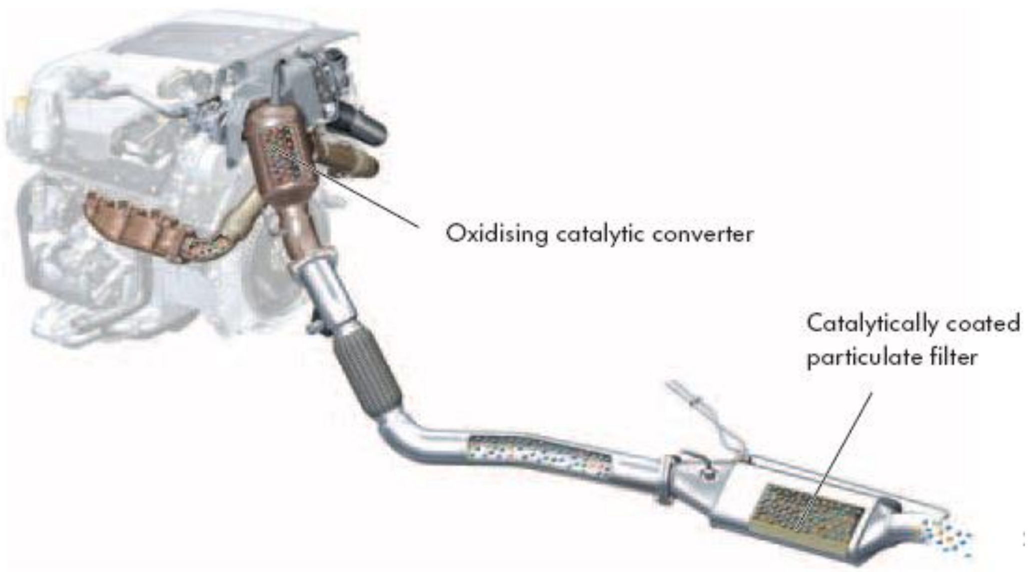
By reducing the amount of excess air available for combustion there is more chance of incomplete combustion. This is normally partially rectified by improved mixing of the air and fuel but there will still be a net increase in particulate matter (PM).

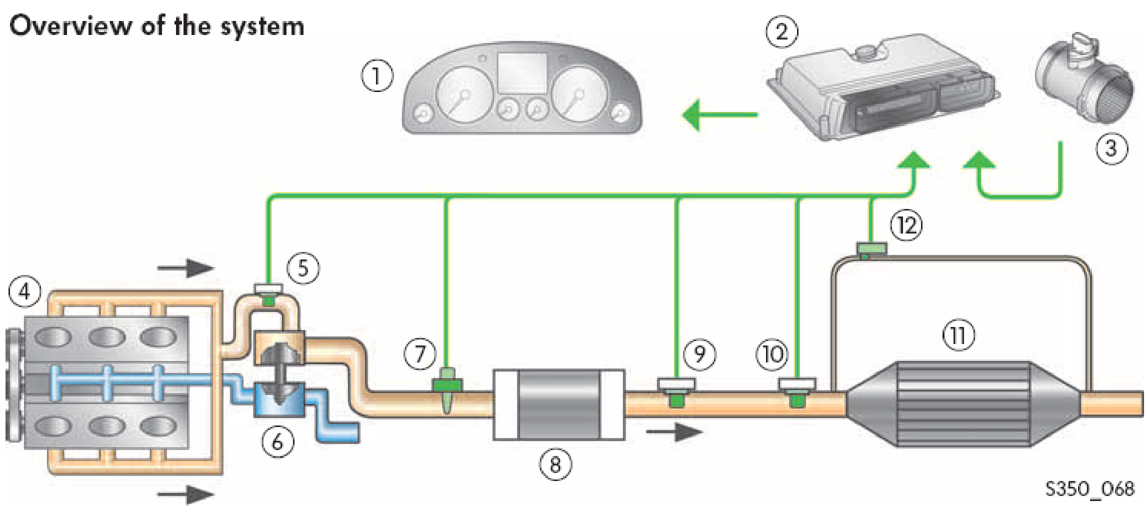
Diesel Particulate Filter



The purpose of the filter is to trap any particulates produced by incomplete combustion. The diesel particulate filter is comprised of a honeycomb shaped ceramic body manufactured from silicon carbide, which is contained in a metal housing. The ceramic body is sub-divided into a multitude of small channels, which are sealed on alternating sides. This results in intake and exhaust channels which are separated by filter walls.

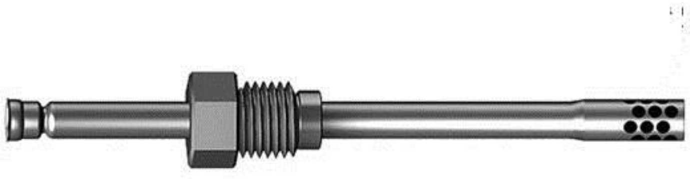
The silicon carbide filter walls are porous and are coated with a substrate comprised of aluminium oxide and cerium oxide. The precious metal platinum, which serves as the catalyst, is vapour deposited onto this substrate. The cerium oxide coating in the particulate filter lowers the carbon's ignition temperature and accelerates the thermal reaction with oxygen. The exhaust gas, which contains carbon, flows through the intake channels' filter walls. Unlike the gaseous components of the exhaust gas, the carbon particles are retained in the intake channels.





(1) Control unit with display in dash panel insert J285
(2) Diesel direct injection system control unit J248
(3) Air mass meter G70
(4) Diesel engine
(5) Exhaust gas temperature sender 1 G235
(6) Turbocharger
(7) Lambda probe G39
(8) Oxidising catalytic converter
(9) Catalytic converter temperature sensor 1 G20 (Phaeton only)
(10) Bank 1 exhaust gas temperature sender 2 G448
(11) Particulate filter
(12) Exhaust gas pressure sensor 1 G450

As long as the temperature remains high enough, the carbon particles will react with NO**x** to produce CO2 and Nitrogen; this is known as passive regeneration. Under low load conditions the temperature drops and soot particles build up in the filter. The degree of restriction to flow is monitored by a differential pressure sensor and when required, the DPF is put into a regeneration mode.



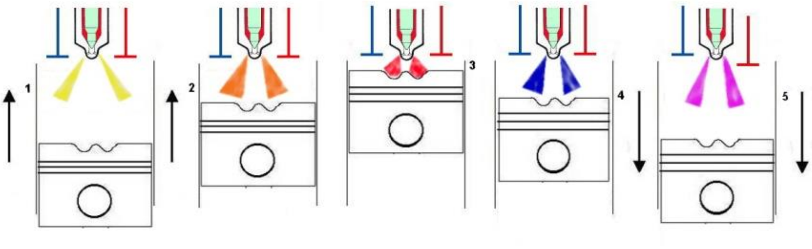
Exhaust gas temperature sensor

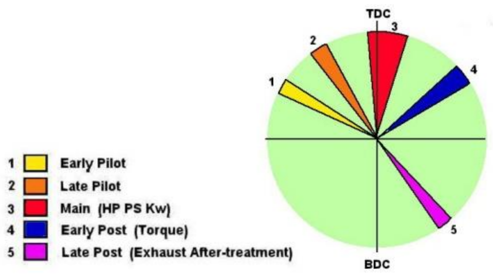
Pressure differential sensor

Regeneration

Passive Regeneration

Regeneration can only happen when the running conditions are suitable. The engine must have been travelling at mid throttle for a period of time. The computer is trying to anticipate a steady situation such as a motorway journey. Regeneration occurs by raising the temperature of the DPF to around 550°C and providing it with extra oxygen. To do this, the computer reduces the EGR system contribution to intake to 0%, ensuring maximum excess air and the electrical consumers such as the heated rear screen, glow plugs and fan unit are turned on to load the alternator. Extra fuel is injected into the cylinder in a late or post injection, which sends hot gasses into the oxidation catalyst and DPF, raising its temperature sufficiently to cause the carbon to react with the excess oxygen and NO2 supplied by the engine. The temperature can be monitored by temperature sensors strategically placed fore and aft of the DPF. A successful regeneration process will continue until the pressure differential across the DPF drops to an acceptable level. Should the driving circumstances change, for instance the car comes to a halt, the regeneration is abandoned until the conditions once again become suitable.





Problems arise when successive regenerations are abandoned and the soot levels build to a point where the DPF becomes restricted - cars that drive around in town traffic or for short journeys are susceptible to this. When it happens, the driver is notified by a warning light, and the vehicle should be taken on a journey that allows regeneration to happen (this should be described in the owner's manual). If the warning is ignored, then a second warning appears or the vehicle may go into limp home mode. This is when the technician must force regeneration.

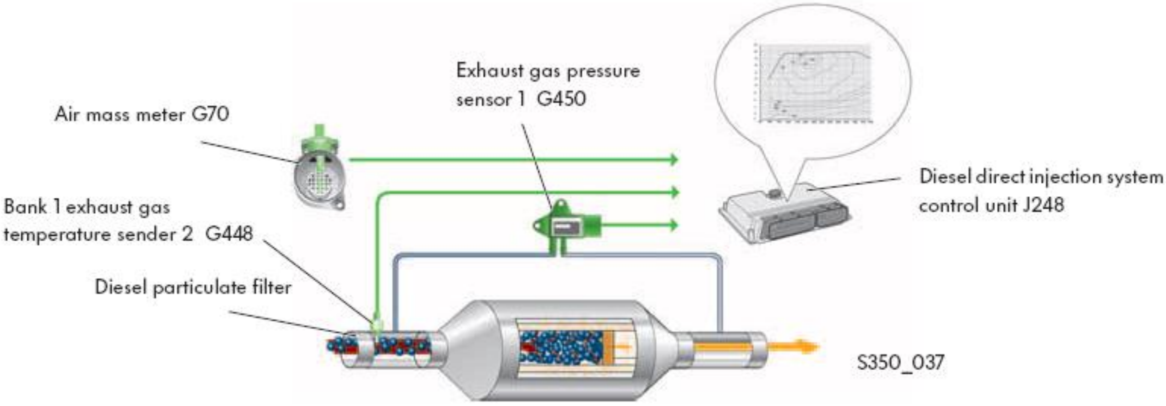
Active Regeneration

In urban traffic, i.e. low engine load, the exhaust gas temperatures are too low for passive regeneration. As no further carbon particles can be degraded, the carbon accumulates in the filter.

As soon as a specific level of carbon has been reached in the filter, active regeneration is introduced by the engine management system. This process takes approximately 10 – 15 minutes. The carbon particles are combusted together with oxygen at an exhaust gas temperature of 600 – 650 °C to form carbon dioxide.

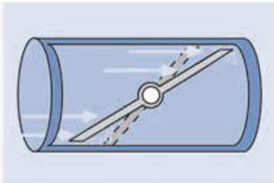
Active regeneration function

The particulate filter's carbon level is calculated by two pre-programmed level models in the engine control unit. One carbon level model is determined from the user's driving style and the exhaust gas temperature sensor and lambda probe signals. The other carbon level model is the diesel particulate filter's flow resistance, which is calculated from the signals output by exhaust gas

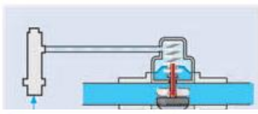


pressure sensor 1, bank 1 exhaust gas temperature sender 2 and the air mass meter.
As soon as the carbon level limit value has been reached in the particulate filter, active regeneration is introduced by the engine management system. The following measures lead to a specific, temporary increase in exhaust gas temperature to approximately 600 – 650 °C. In this temperature range, the carbon collected in the particulate filter oxidises to form carbon dioxide.

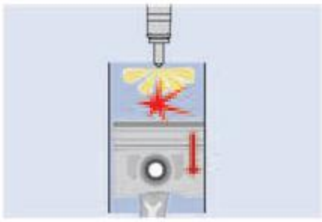
The intake air supply is regulated via the electric throttle valve.



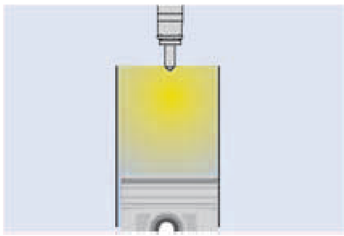
Exhaust gas recirculation is switched off to increase the combustion temperature and the oxygen content in the combustion chamber.



Shortly after "retarded" main injection, the first secondary injection is introduced to increase the combustion temperature.

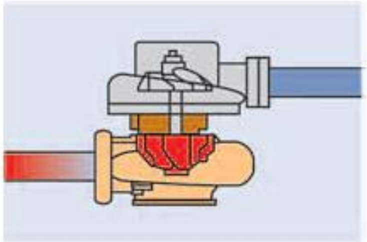


Further secondary injection is introduced long after main injection. This fuel does not combust in the cylinder, but evaporates in the combustion chamber. The un-combusted hydrocarbons contained in this fuel vapour are oxidised in the oxidising catalytic converter. The heat which is generated during this process increases the exhaust gas temperature upstream of the particulate filter to approximately 620 °C. The engine



control unit uses the signals transmitted by the bank 1 exhaust gas temperature sender 2 or catalytic converter temperature sensor 1 to calculate the injection quantity for retarded secondary injection.

The charge pressure is adapted to prevent the driver from noticing a perceptible change in torque during the regeneration process.

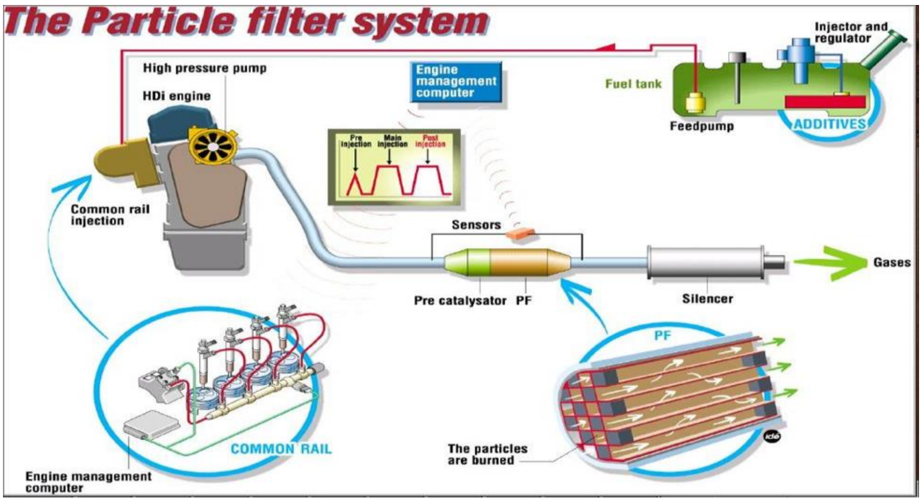


Forced Regeneration

Forced regeneration can only be done with the scan tool and certain conditions must be met, depending on the vehicle. Some forced regenerations can only happen when the vehicle is being driven so details of the process must be investigated. Standing regeneration can be a noisy affair as the engine revs to 4000rpm for up to 4 minutes then to 2000rpm for a further 4 minutes. The heat generated causes unusual burning smells. It is better performed with the vehicle raised and a fan blower providing some air movement underneath the vehicle.

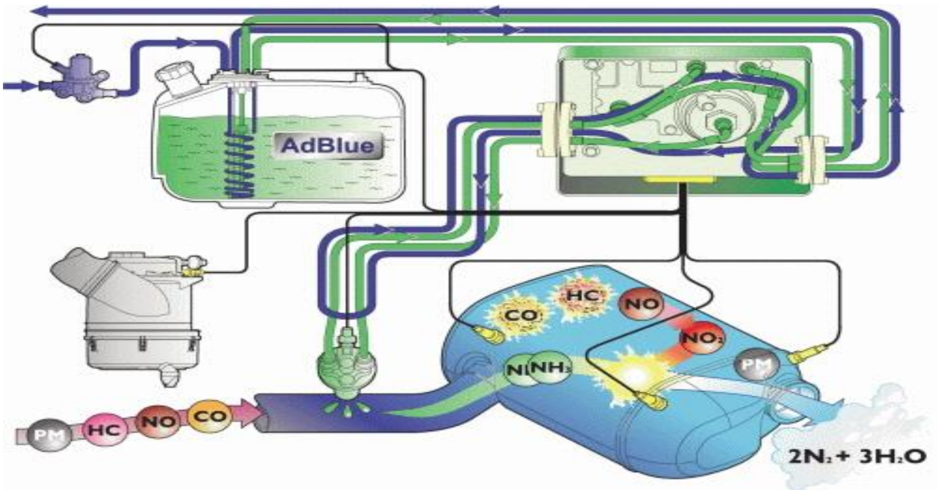
Eolys

Eolys is a pre-treatment used by Peugeot/Citroen to make regeneration of the DPF more effective. It reduces the temperature at which carbon particles react with oxygen from around 550°C to 450°C. The active ingredient is an iron and/or cerium rich compound in solution with a combustible solvent. A small quantity is added automatically from a separate tank to the main fuel tank every time the vehicle is re-fuelled. The active ingredient goes through the combustion process and is deposited in the DPF. Eventually the DPF will become blocked with the deposit and will need to be replaced - the life span of a DPF fitted to this system ranges from 75,000- 120,000 miles depending on the model.



Selective Catalytic Reduction (SRC)
AdBlue systems

There is another approach to reducing the NOx. EGR reduces the efficiency of the engine and promotes particulates. Future Euro regulations call for not only a reduction in PM measured by mass but also for a reduction in the number of particles. The reason for this comes from research into the effect of nanoparticles, which has shown that, unlike larger soot particles, these tiny carbon particles, are not expelled from the lung, and can cause serious health problems. SCR is an alternative to EGR which addresses this problem. It has been used on commercial vehicles for some years now and is a proven method of reducing NOx. It is now used by VAG and Mercedes on their passenger cars.



AdBlue is a solution of 32.5% urea and water contained in a separate tank on the vehicle. It is not a fuel additive but instead is injected into the exhaust after the oxidising catalyst and DPF. When the urea meets the hot exhaust gasses it decomposes to ammonia (NH3) and CO2**.** The ammonia then reacts with the oxides of nitrogen in a second catalytic converter to form Nitrogen and water. The advantage is not only a reduction in NOx of about 85%, but a reduction in the use of EGR means a more efficient combustion, reduced PM and improved fuel consumption.

Petrol/Diesel Engine mechanical symptoms and faults
Poor performance

Worn mechanical components will have a significant effect on the performance of the engine. In order for that engine to operate efficiently a number of physical movements take place. The engines mechanical components rely on the lubrication system and the cooling system to ensure the correct operation of the moving parts. If any single component starts to fail it will have an effect on the overall operation of the engine. This effect makes diagnosis often difficult as the root cause has to be evaluated as the primary cause and the damage or failures that result from this have to be evaluated as secondary failures.

Engine noises
Unusual and excessive noise

Diagnosis of engine noise can be difficult, a stethoscope or a rubber hose (a metal rod can also be used) can be a useful tool that will help in locating where the noise is coming from since the noise will travel through a hose or along a metal rod with ease.
Diagnosis of engine noise is nothing more than splitting the possibilities down to only one. It is important to eliminate engine accessories such as those driven by the fan belt, alternators, air-conditioner compressor or power steering pump. Removing the belt of belt driven accessories is a useful way of identifying where the noise is coming from any of these components.
Note: all diesel engines produce a ‘knocking’ sound when running (diesel knock). In a diesel engine fuel ignites when injected into the heated compressed air in the combustion chamber. This rapid combustion causes very high pressures, which generate a rumble or dull clattering sound, this is normal. Some types of fault within the fuel injection system cause the knocking noise to increase.

Exhaust leaks

Blocking off the exhaust system momentarily increases the rate of ‘blow’ from the exhaust pipe, the noise may be a severe blowing sound or in the case of slight leaks the exhaust may hiss while its exit is blocked, also check the exhaust manifold and any accessory connected to it such as the oxygen sensor and exhaust gas re-circulating valve etc.

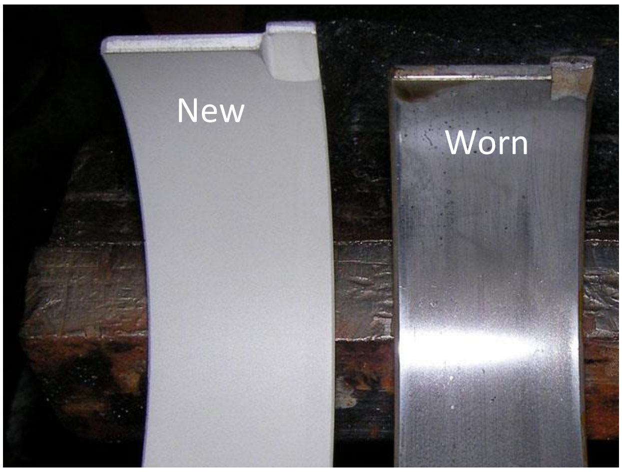
Top of the engine

Tappets are the most likely cause of noise from the top of the engine, incorrect clearances (too wide) are the most common fault but it is important not to rule out camshaft and valve lifter (cam follower) wear.

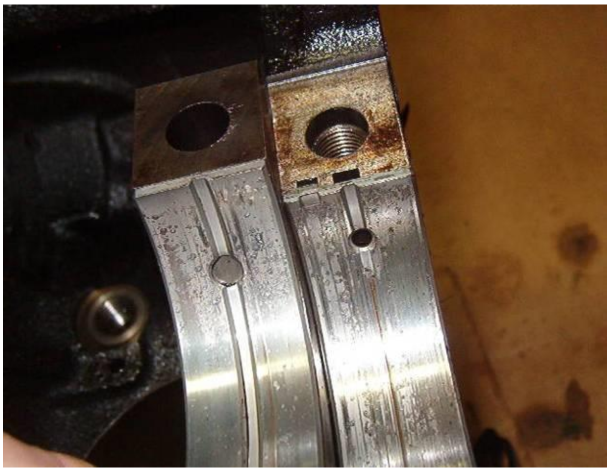
Bottom of the engine

Noises from lower down in the engine are normally caused by worn big end bearings, which knock on over run and acceleration the noise reduces when the engine is lightly loaded.
Rumbling noises indicate that the main bearings are possibly worn. Big end bearing wear diagnosis is helped by the fact that it is accompanied by low oil pressure (use an oil pressure gauge to help diagnose the problem).
Experience plays a large part in correct diagnosis of engine noise, which can only come with practice and having heard the noise first hand.

Worn big end bearing



Worn main bearings



Engine mechanical fault table

Wear type	Remedy
Worn valve mechanism (Loud tapping or rattling noise from the cam cover)	Inspect valve gear for signs of lubrication and/or physical damage. Repair as necessary.
Worn crankshaft bearings (Heavy knock under engine load (big end)or constant rumbling and heavy rattle)	Disassemble and inspect for signs of excessive wear. Measure and evaluate crankshaft bearing for serviceability. Evaluate excessive end float in the crankshaft. Repair as necessary.
Worn timing gear/chain (Rattle from the timing gear area of engine)	Disassemble for access and evaluate timing gear/ chain and tensioner for signs of insufficient lubrication or physical damage. Check oil pressure against specification.

Bent con rod

Damage to engine block

Erratic running or low power

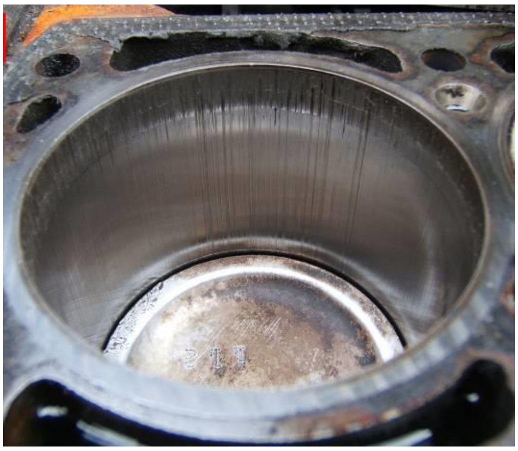
Erratic running is often referred to as a ‘misfire’ which means that the powers stroke never occurred correctly. This causes the engine to lose power and the driver will notice quite quickly that something is wrong. Diagnosis of a ‘misfire’ is broken down into two areas, mechanical misfire and a fuel misfire. Exhaust emissions and a keen nose will help with evaluating the root cause.
Diagnosis of a petrol misfire involves removing the spark plug (ensuring the sparkplug lead is away from the cylinder hole) and cranking the engine. After cranking, check for signs of fuel in the bore. Note: excess cranking can cause the bore lubrication to be washed away causing physical damage.
Diesel diagnosis is often difficult as a diesel engine has no sparkplug. Diesel can be checked at the injector if it is not a common rail system by cracking the injector supply pipe. If the diesel engine is a common rail type a diagnostic tool must be used to read fuel rail pressure and other fuel data. Note: common rail diesel fuel systems are very dangerous and can easily result in injury or death. Always observe the safety precautions defined in the technical instructions.
If the fuel system is diagnosed to be in working order, a compression check or a cylinder leakage test should be carried out to determine cylinder integrity.

Lubrication system faults

Lubrication system faults can range from the obvious seal leak to very difficult to diagnose internal problems that often cause faults associated with other systems first. Correct diagnosis of a lubrication system can avoid costly repeat repairs as the final test of mechanical components often assumes that the lubrication system is fully functional.

Excessive oil consumption

Oil is the blood of an engine and if it is lost in any way it will lead to increased component wear and possible failure.
Oil can be lost through seal failure causing the oil to be lost externally. This can range from a faulty or poorly fitted oil filter to a small internal ‘o’ ring leak. If excess piston ring wear occurs causing the cylinder bore to become worn, oil can travel past the piston rings and become part of the combustion process. This can eventually lead to total engine failure.



Oil can enter the cooling system if the cylinder head gasket fails and potentially cause emulsification. Emulsification is where the two materials do not blend easily and form an unstable mix like a cream. The cream blocks oil ways causing lubrication failure to vital moving parts, resulting in excessive wear and eventual seizure. Small bore coolant pipes as well as cooling galleries in the radiator and heater matrix become blocked, no longer allowing the coolant to dissipate the heat of combustion.

Cooling system faults

The cooling system used for the engine is a pressurised sealed system. This means that any leak no matter how small will cause problems due to the system no longer being sealed or being able to maintain pressure.
A cooling system pressure tester can be used to simulate the engines running pressure. This allows you to check all the external system parts for leakage. Be sure to check every component and joint for leakage.
If the cooling system has an internal leak it can be burned in combustion and become steam or it can mix with the oil galleries and become a thick yellow cream (emulsification).

Thermostat (coolant regulator) faults

If the thermostat is stuck in the closed position it will cause the engine to overheat as the cylinder coolant will not be able to flow into the radiator and exchange its heat with the air. This will cause the coolant to boil and create large amounts of steam usually seen from under the bonnet coming from the pressure cap.
If the thermostat is stuck open the vehicle will remain excessively cool, causing warm up periods to increase. This will lead to the engine requiring more fuel to overcome the cylinder quenching (vaporised fuel becoming droplets) caused by cold running. This will have a negative effect on performance and fuel efficiency.

Core plugs

Core plugs are fitted to the engine assembly to prevent major failure. Due to the fact that as coolant deteriorates over time the freeze point returns closer to 0°C. This means that if the coolant freezes in the engine it will expand. This expansion will cause the internal castings to fracture. To overcome this potential disaster plugs are fitted around the cylinder walls to allow expansion should the coolant freeze. The plugs are of interference fit type and simply pop out should expansion occur.

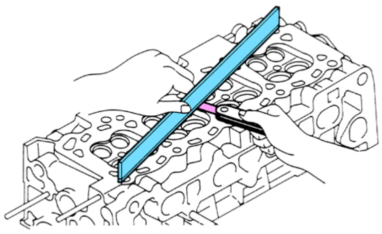
Repair tip

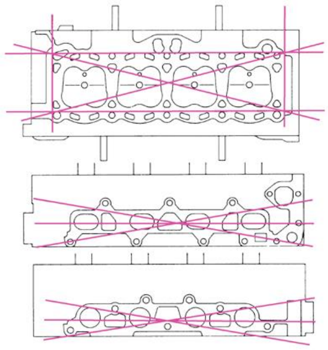
During maintenance the core plugs should be checked for signs of excess corrosion and leakage.

Checking the surface of a cylinder head and block for distortion

Clean all mating parts thoroughly. Excessive scraping can damage light alloy metals therefore use a chemical gasket remover and flush all oily parts with residue free brake cleaner, or use a similar cleaner

Using a straight edge and feeler gauge measure the gap between the feeler blade and the straight edge as indicated.





Using a precision straight edge and feeler gauge, measure the surfaces that come into contact with the cylinder block and manifolds for distortion.

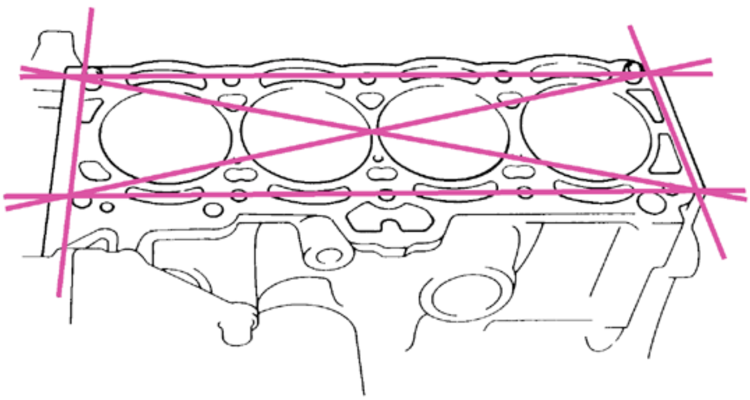
Maximum distortion:

Cylinder block side	**0.05mm (0.0020 in.)**
Manifold side	**0.10mm (0.0039 in.)**

If the distortion is greater than the maximum, replace the cylinder head.

Clean all mating parts thoroughly. Excessive scraping can damage light alloy metals therefore use a chemical gasket remover and flush all oily parts with residue free brake cleaner, or a similar cleaner.

Using a straight edge and feeler gauge, measure the gap between the feeler blade and the straight edge.



Measure the surface which is in contact with the cylinder head gasket for distortion in the same way as for the cylinder head.

Maximum distortion: 0.05mm (0.0020 in.)

If the distortion is greater than the maximum, replace the cylinder block.

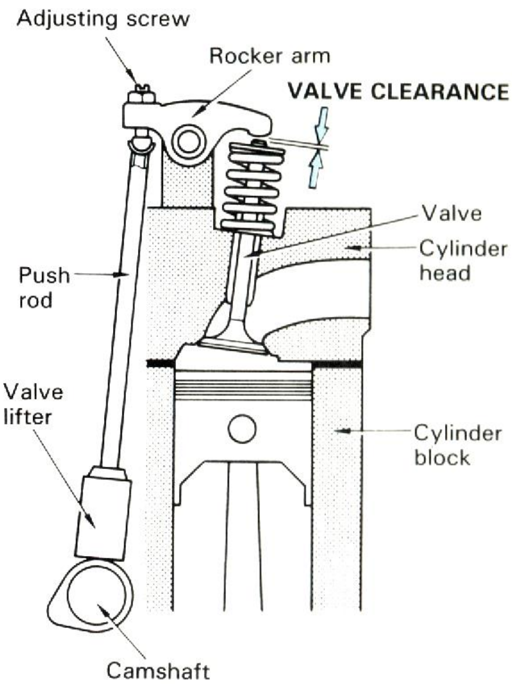
Engine valve oil seals

Overhead valve mechanisms require oil seals to prevent oil from trickling down the valve stem or in the case of the inlet valve, being drawn into the cylinder when the piston is on its induction stroke.
Oil consumption rises and emissions become a concern as the valve stem and guide become worn over time. Oil seals that have reached the end of their serviceability, worn valve guides and stems can normally be detected by allowing a warm engine to stand idle for a time, then starting the engine up and watching for blue smoke being emitted from the exhaust system when the engine speed is increased rapidly.

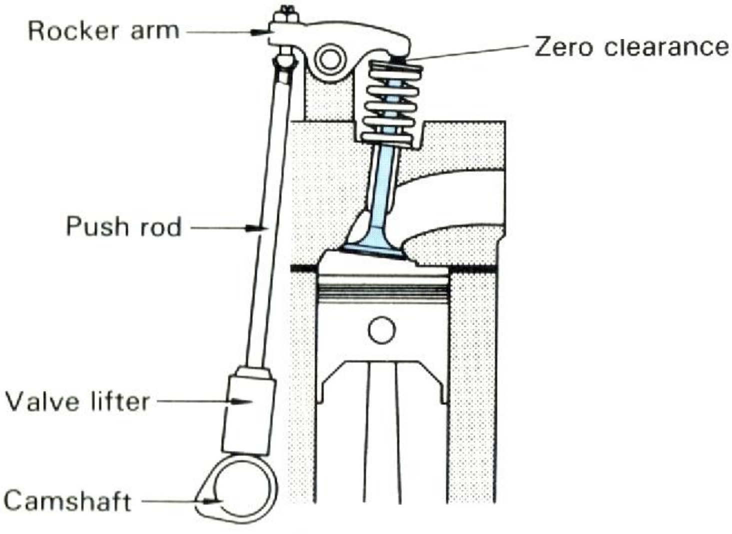
Valve clearances

Valve clearances are necessary because the cylinder block, cylinder head, valves and valve mechanism expand when heated and contract when cooled, the valve clearances are specified by the manufacturer, they state whether the clearances should be measured with the engine hot or cold.

Excessive clearance results in noisy operation and will lead to excessive wear.

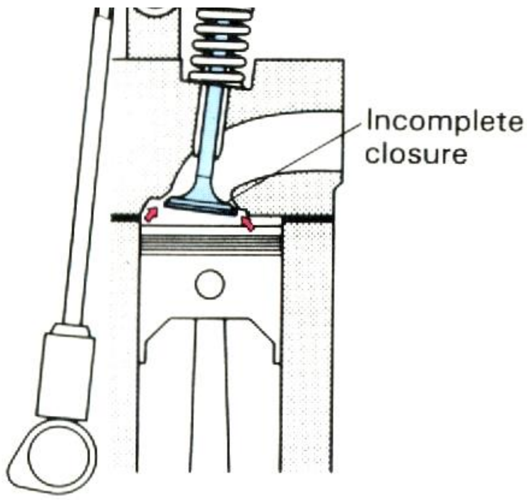


No clearance between the valve mechanism and the valve is shown opposite.



ENGINE COLD

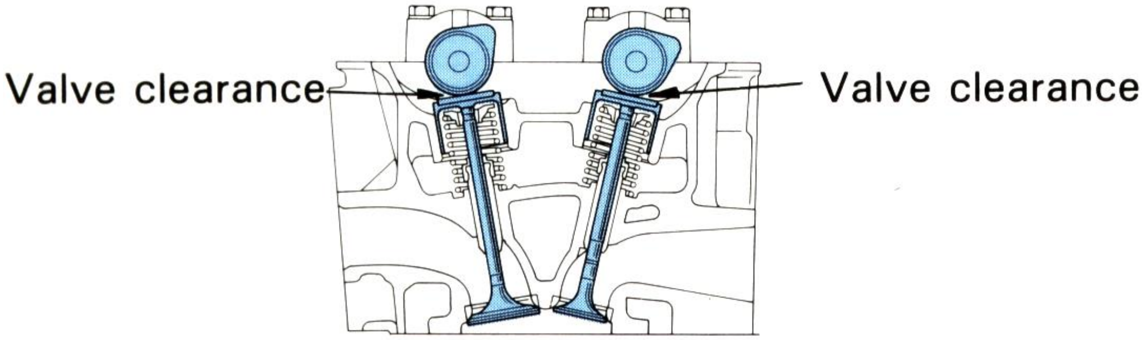
Too little clearance may result in the valve not closing properly under certain conditions; this will lead to escape of gas through the exhaust valve, less seat contact and less heat dissipation through the seat, which may lead to burning of the exhaust valves, leading to loss of compression, power and uneven running.



ENGINE HOT

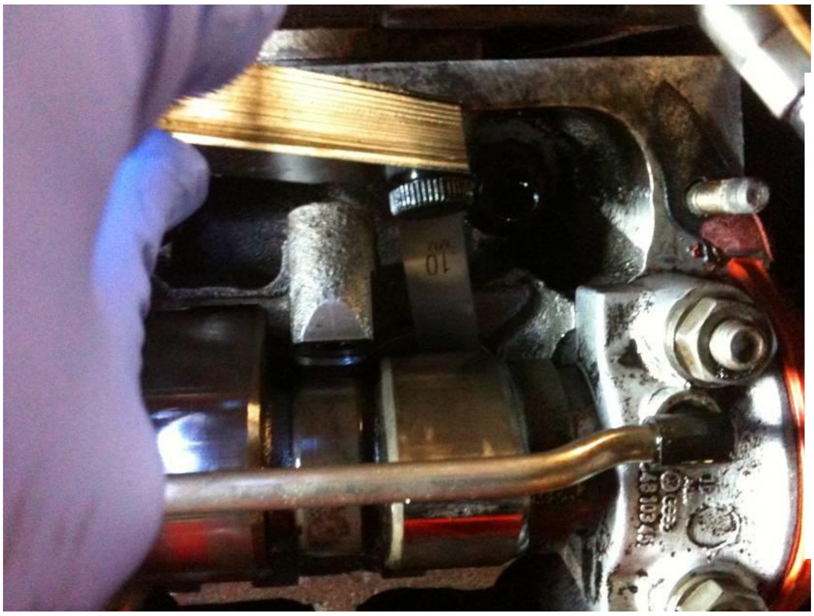
If the rate of expansion is greater in the valve mechanism than the cylinder head and block, the valve will not close completely. Valve clearance is provided to prevent this.

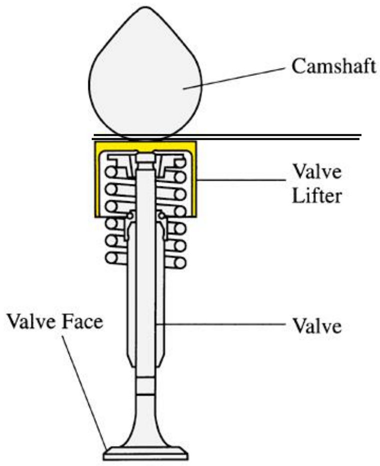
For efficient engine operation valves should make an airtight fit when they are in contact with their valve seats when they are closed. If valve clearances are not maintained the performance of the engine suffers, it is therefore necessary to check and adjust the valve clearances periodically.



Valve clearances may be checked when the engine is hot or cold depending upon the manufacturers recommendations the adjustment method also varies.

Adjusting Valve clearances





When checking valve clearances, the cam lobe should always be on the back (or side) this ensures the valve is in the rest position.

With experience, you will develop a 'feel' for the correct amount of resistance when adjusting the clearances. Always use the manufacturer's specified tolerances.

Decarbonising

Reasons for decarbonising engines
Residue from burnt fuel and lubricants (carbon deposits and impurities) are detrimental to the operating performance and economy of an engine.
Carbon build up can affect the engine in the following ways:

- Poor starting
- Uneven idling
- Loss of power
- Increased fuel consumption
- Misfiring
- Engine wear.

Carbon around the valves and burnt pitted seats cause severe problems, which needs to be addressed with a degree of urgency. The problem is compounded when the seals around the valve stems are worn allowing oil to build up on the valves which then become coated with carbon due to the oil being partially burnt, this build-up of carbon deposits can interfere with the air flow into the engine cylinders.
Some companies sell products and claim that these products can decarbonise an engine, it is not intended to provide an argument for or against such products but it should be noted that when and engine is in need of decarbonising, it is normally required, that the engine cylinder head is removed to allow carbon deposits to be removed and to fit new valves, or when permitted, resurface the valves and their seats.

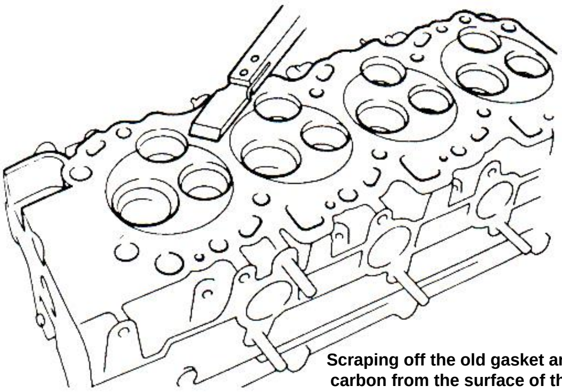
Removing the valves

After removal of the cylinder head the exhaust and inlet valves can be removed using a special service tool (valve spring compressor). The valves must be kept in order of removal if they are to be reclaimed. Many cylinder heads are made from aluminium alloy therefore extra care must be taken to prevent damage to the cylinder head surface.

Cleaning the cylinder head surface

After removal of the valves the surface of the cylinder head can be cleaned, by scraping off traces of the old gasket**.**

For aluminium surfaces use a plastic or wooden scraper. Never attempt to clean gasket surfaces using grinders,



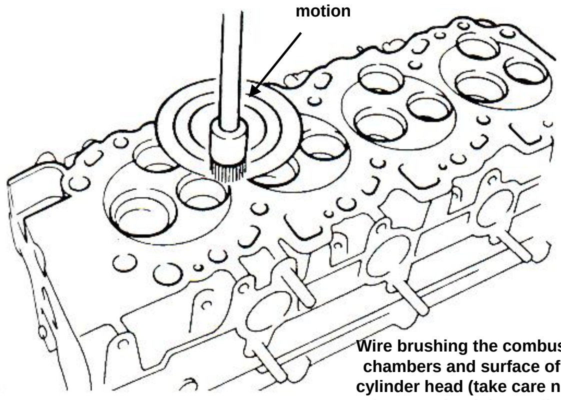
Scraping off the old gasket and carbon from the surface of the cylinder head

rotating steel brushes, oscillating grinders or tools with cutting edges, these tools will allow grinding dust and gasket residue to enter the engine's oil passages and will cause deformation at the gasket surfaces leading to oil, coolant and compression leaks. A vacuum cleaner can be used to prevent contaminants and gasket residue from entering the engine by holding the cleaner above the working tool.

Removing carbon

The valve ports can be cleaned using a wire brush, (refer to precautions noted above for aluminium engines) use a rotary motion.

Occasionally it may be necessary to use the scraper on stubborn areas. Don't forget to take care, do not cause damage to the surfaces of the cylinder head or block.

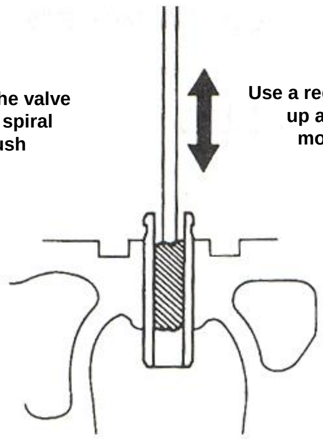


Wire brushing the combustion chambers and surface of the cylinder head (take care not to damage aluminium cylinder heads)

Cleaning the valve guides

It is necessary to remove carbon from the valve guides because it could cause the valves to stick during service.

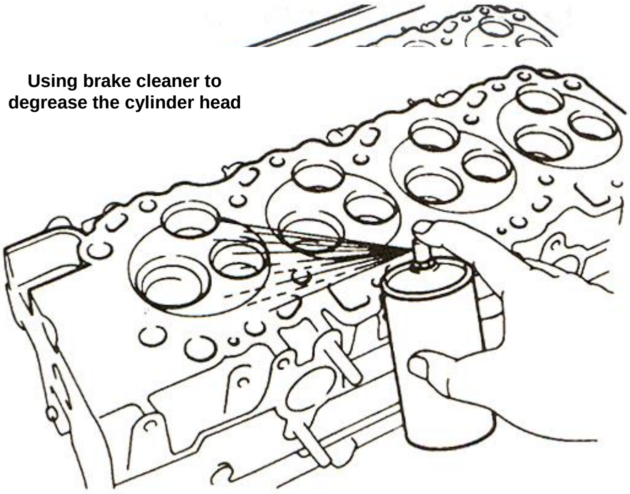
The specially shaped wire brush must not be too tight in the guide, and should be moved up and down slowly as the brush rotates. Do not prolong this cleaning just do enough to rid the guide of carbon otherwise unnecessary wearing of the guide will take place.



Wire brushing the valve guide using a spiral shaped brush

Degreasing the cylinder head

Using a degreasing plant removes all traces of lose carbon, oil and debris from the cylinder head.

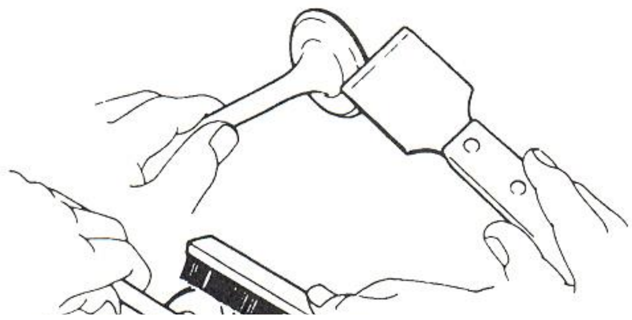


Using brake cleaner to degrease the cylinder head

If a degreasing plant is not available then using a brake cleaner solvent or similar is advised. (the cleaner used must not leave a residue upon evaporation; any residual material could lead to sealing problems).

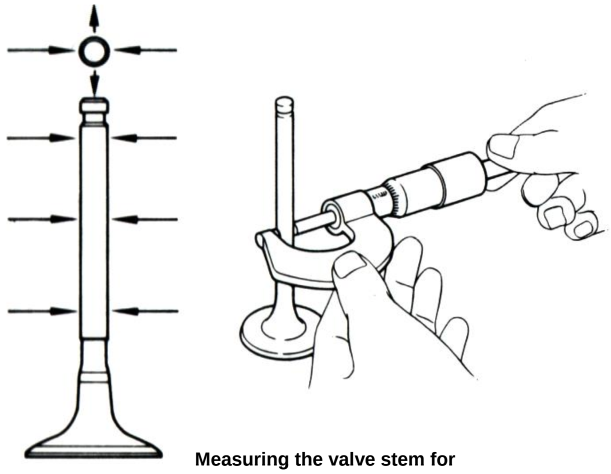
Cleaning the valves

The valves are cleaned using a wire brush and scraper.



Checking the valve for wear

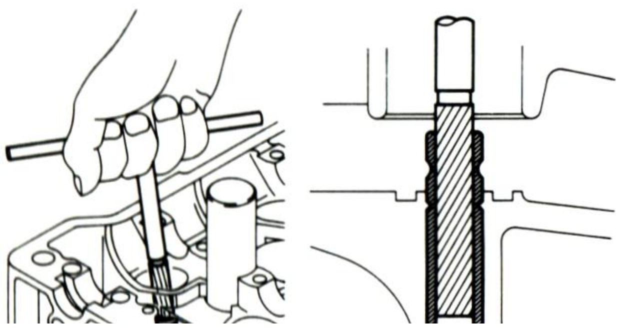
Using a micrometer, measure the valve stem diameter and note any wear. Replace if worn.



Measuring the valve stem for wear

Check valve guides

Check valve guides for wear.
Use of a guide reamer to obtain the correct clearance between the valve stem and the guide a reamer is used. If the clearance is less than specified the valve could stick, if more than specified the oil seal may leak oil into the combustion chamber, therefore affecting emissions, if the clearances is severe, noise may result. Poor seating of the valve and valve leakage could be caused.



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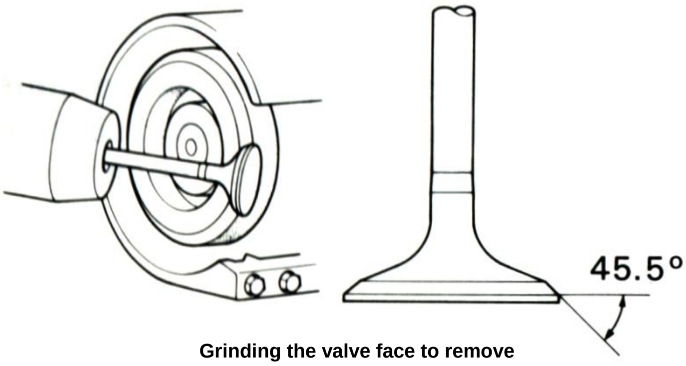
Re-surfacing the valve seats

Grind the valve just enough to remove the pits, ensure that the valve grinder is set to the correct angle supplied by the manufacturer for the valves being refaced.

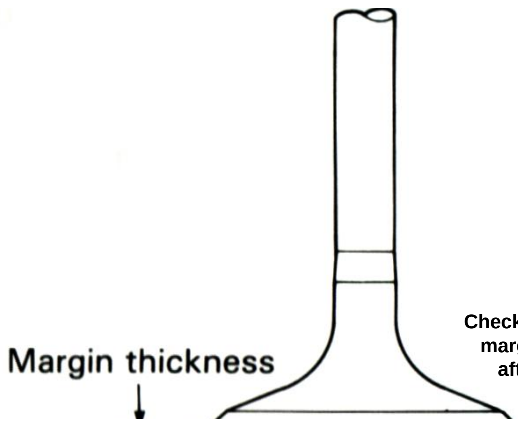
Some valves cannot be re-faced due to a special surface that has been applied to the valve seat during manufacture these valves must always be replaced.



Grinding the valve face to remove pits from the valve seat and to obtain the correct angle

Checking margin thickness

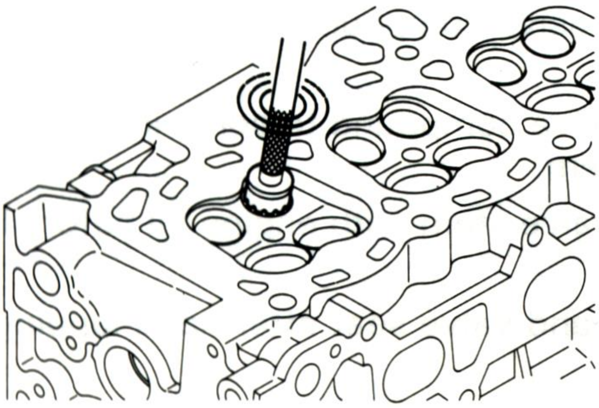
Margin thickness must be within specification, if the margin is too thin, the valve strength will be lost which may cause the valve to form a tulip shape at the head due to constant hammering as the valve contacts the seat when it closes (it may fold over). The valve will also overheat on the edge of the margin leading to burnout.



Checking valve head margin thickness after grinding

Cutting the valve seats

Using a carbide cutter re-surface the valve seats. Only remove enough metal to clear the seat of the pits.

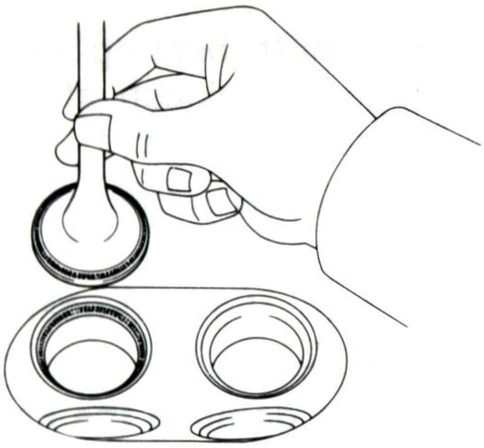


Using a carbide cutter to resurface the valve seat

Checking the valve seat position

By applying ‘engineers’ blue or white lead to the valve face correct seating of the valve can be checked.
Without rotating the valve press it into the seat using light pressure, remove the valve and examine the seat. The valve seat should be marked equally around 360 degrees of the mating surfaces indicating that the valve is concentric if this result cannot be achieved then a new valve must be fitted. It may be necessary to re-surface the seat.

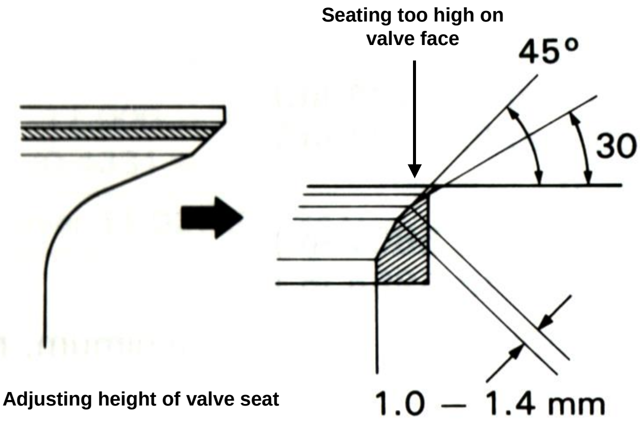
Checking that the valve is seats correctly



Checking valve seat contact

Check that the valve seat contact is in the middle of the valve face and is at least 1mm wide.

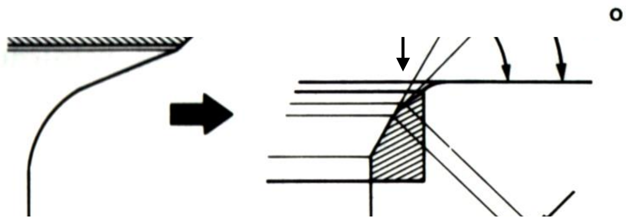
If the seat is too high on the valve face use a 30 degree and 45-degree cutter to correct the position of the valve on the seat.



Adjusting height of valve seat

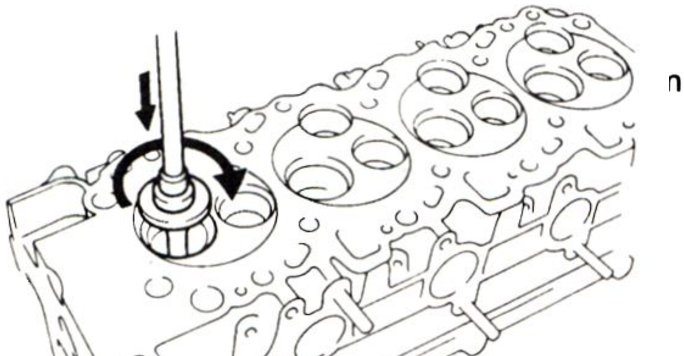
Checking valve seat contact

If the valve seat is too low then use a 60 degree and 45-degree cutter to correct the problem.



Lapping the valves

Using a rubber sucker type valve lapper, lap the valve and seat using abrasive compound on the seats, do not use too much since it may get on the valve stem.
Putting oil on the stem helps to wash off any small amounts of abrasive compounds and provides a



Lapping in the valves rotating clockwise and anticlockwise lifting occasionally

means of ensuring that the valve rotates smoothly.
The valve -lapping tool should be rotated backwards and forwards, occasionally lifting it off the seat and turning the valve at least 90 degrees, replacing the valve in the seat and continuing lapping using light pressure.

Although it may seem difficult at first, soon, a rhythm will develop. Using pencil marks on the valve seat, rotating the valve and examining the marks, which should be cut where the valve is seating, is a good indication of the condition of the valve and seat during lapping.

Lapping in the valves using a rubber sucker

It is essential that the abrasive compound is cleaned off and renewed at regular intervals while lapping.

Compression testing

Compression is a process in which air or air/fuel is squeezed into a smaller volume e.g. in the combustion chamber. Molecules are forced together under high pressure.

In petrol engines, the pressure is usually about 13.16 bar (191 psi, 1320 kPa).

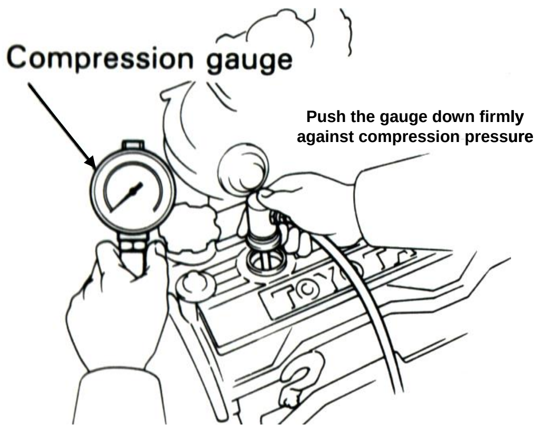
In diesel engines, the pressure is usually about 30.68 bar (445 psi, 3,138 kPa).

The compression pressure depends upon the size and power of the engine. Manufacturers provide specific compression pressure specifications.
If the compression pressure is too high in a petrol engine it can cause pre-ignition and detonation which leads to engine noise and damage to components such as bearings and pistons. If the compression pressure is too low, loss of power will result, fuel economy suffers and exhaust emissions may not satisfy legal requirements. Diesel engines rely heavily on the compression pressure to raise the temperature of the air to ignite the

diesel fuel so if the pressure is too low difficulty starting and loss of power is the result. Exhaust smoke and legal requirements regarding exhaust emissions may not be met.
Compressions should be checked if the engine is running uneven or lacking power etc. By performing a compression test internal engine malfunctions such as leaking valves, piston rings worn or excessive carbon build –up can be detected. Before compression testing ensure, that the valve clearances are checked.

Compression test - petrol engine

Warm up the engine
Disable the ignition and fuel injection system including the cold start injector, if fitted this will prevent an excess of fuel building up in the engine cylinder and catalytic converter (exhaust system)
Remove the spark plugs



Insert the compression tester into the spark plug hole.

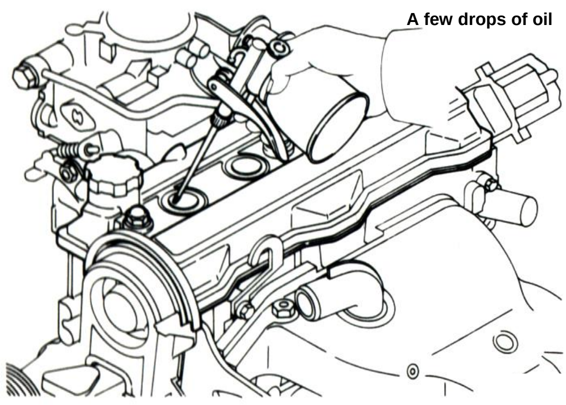
Hold open the throttle to ensure adequate air-flow into the cylinder

Crank the engine using the starter motor for about 10 revolutions to obtain the highest reading on the compression tester

Note readings for each cylinder, compressions should not vary between cylinders of more than 10 percent

Safety first: Wear eye protection and gloves.

If the compression in one or more cylinders is low, pour a small amount of engine oil, into the suspect cylinder through the spark plug hole. Repeat the compression test.



If adding oil increases the compression pressure it would most likely mean that the piston rings and or cylinder bore are worn or damaged. If the pressure remains low the problem is most likely a sticking or burnt valve (not seating properly), or the cylinder head gasket may be leaking.

Compression test - diesel engine

Warm up the engine

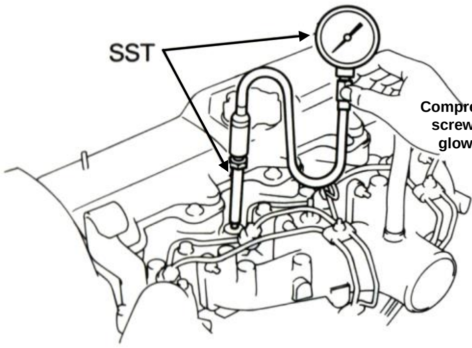
Disable the fuel system

Remove the glow plugs and injector pipes if necessary

Screw the compression tester into the glow plug hole (note the petrol engine compression tester must not be used on diesel engines)

Open the throttle fully

Crank the engine and note the compression pressure tester reading (ensure that the battery is fully charged otherwise full cranking speed may not be achieved)



If the pressure in one or more cylinders is low pour a small amount of oil into the cylinder through the glow plug hole and repeat the steps above. If adding oil increases the compression pressure, the piston, piston rings and cylinder bore may be worn or damaged. If the pressure stays low, a valve may be sticking or not seating properly or the cylinder head gasket may be worn.

Safety first: Wear eye protection and gloves.

Lack of pressure could be caused by:
- Sticking, worn or broken piston rings
- Wear or damage to the piston and cylinder
- Defective valves
- Cylinder head gasket leaking
- Pressure leakage at the injector nozzle or glow plug
- Bent connecting rods.

A drop-in compression will lead to a lower air temperature during the compression stroke, which in turn will lead to incomplete combustion of the fuel. Wasted fuel produces white smoke in the exhaust. The ignition delay period will be lengthened causing diesel knock, loss of power output, which will cause excessive fuel consumption.

Excessive carbon build-up causes an increase in compression pressure (this can be offset by leaking valves), which can only be rectified by decarbonising the engine.

Cylinder leakage test

A cylinder leakage test is a more thorough way of pin pointing a loss of compression.

Cylinder leakage test example

Remove the spark plugs

Ensure that the piston is at top dead centre (see setting tappets)

Screw the air supply pipe into number one spark plug hole, fit whistle to indicate when the piston is approaching TDC, rotate engine to TDC position both valves closed (compression)

Connect the gauge to airline pressure and adjust the modulator knob to zero the gauge

Connect the air feed pipe to the air supply pipe and allow air to enter the cylinder (take care that the piston is not forced down the cylinder due to the air pressure which should be about 5 kg/cm^2 (70 psi). It may help to put the car in gear with the hand brake on (care must be taken)

Listen to where air is leaking from the following areas:

Remove the oil filler cap and listen for air escaping, about 20 percent is allowed from here, this figure will vary depending upon engine size, more leakage is acceptable on larger engines. Too much leakage means that the piston rings and cylinder bores may be worn. (there will always be leakage past the piston rings due to the piston ring gaps, take care not to wrongly diagnose worn bores and piston rings because of this slight leakage)

Listen at the tail pipe, any leakage here means that the exhaust valve/s are leaking, no leakage is allowed past the exhaust valves

Listen at the intake manifold with the throttle valve held fully open any leaks here means that the inlet valve/s are leaking no leakage is allowed past the inlet valves

Check to see if any bubbles appear in the engine coolant by removing the radiator cap, it may be necessary to over fill the cooling system for this test. Remember to remove the excess coolant after the test and to check the antifreeze mixture for correct strength. Bubbles in the coolant means that

the cylinder head gasket could be leaking or a crack has developed in the cylinder block or cylinder head.

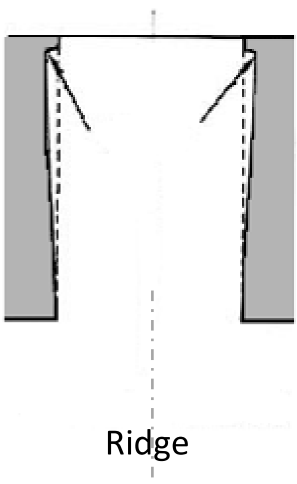
Rotate the engine and repeat the test on the remaining cylinders in correct firing order to avoid rotating the engine unnecessarily.

Lack of power (low compression) fault table

Component failure	Cause
Leaking exhaust valves	Causes can include Incorrect valve timing, valve damage, wrong fuel type incorrect ignition timing
Leaking inlet valves	Causes can include Incorrect valve timing, valve damage, wrong fuel type incorrect ignition timing
Sticking valves	Causes can be the result of, wrong oil type or lack of lubrication causing damage to the stem causing it to bend
Broken valve spring	Usually results in engine failure as the valve drops into the cylinder and contacts with the piston. Can lead to cylinder head failure as the valve becomes embedded into the cylinder head.
Worn piston rings	Usually results in low compression and excessive oil burning due to the large gap created allowing oil to remain above the piston. Can cause excessive amounts of blue smoke to be emitted from the exhaust
Leaking cylinder head gasket	Can cause low cylinder compression as well as steam from the exhaust (burning coolant), over pressurised cooling system, oil and water mixing (emulsification), possible engine component wear and vehicle may be difficult to start.

Engine wear
Piston slap

To allow pistons to move freely in the cylinder a clearance is created. The down side of having a clearance is gas will travel past the piston from the combustion chamber. Because the greatest leakage occurs when the pressure and temperature are at

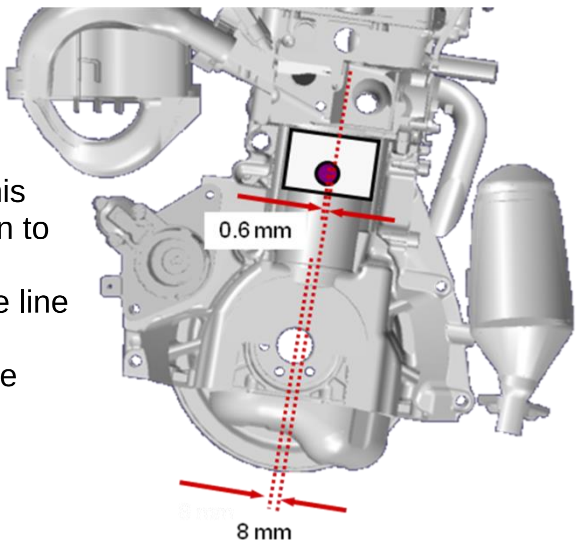


Ridge

their peak during combustion and power strokes, most of the oil that lubricates the piston will be burnt. To reduce this effect the piston will be fitted with piston rings. The rings expand out so they contact the cylinder wall. Most metals expand with a rise in temperature. This means that the clearance around the piston will decrease as the engine reaches normal operating temperature. Large clearances especially when the engine is cold lead to excessive lateral movement. This side movement is at its greatest when the connecting rods angle changes. The piston noise is referred to as 'slap' and can result in excessive piston and cylinder wear.

Major thrust

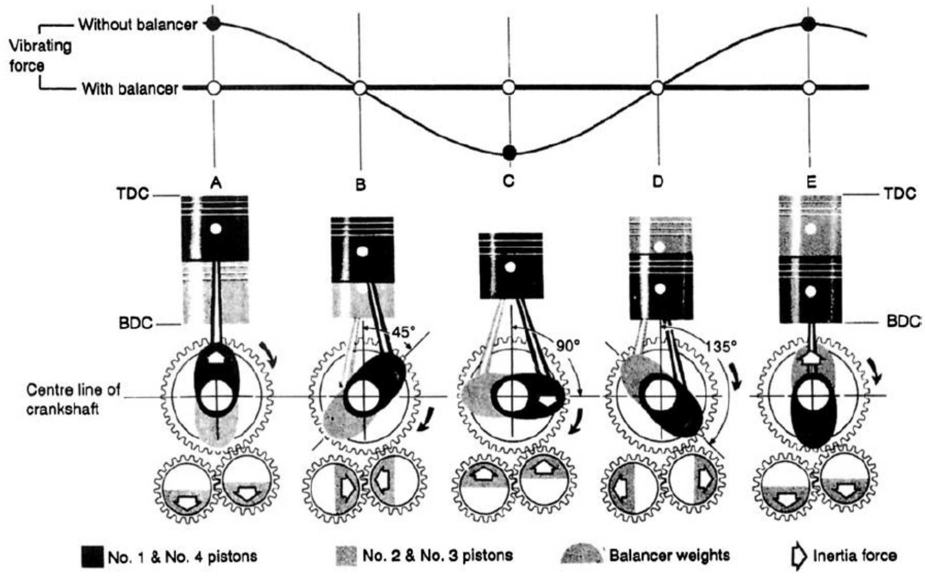
Cylinder wear occurs greater on the major thrust side of the cylinder wall. This is due to the pressure of combustion during the power stroke acting on the cylinder centre line. During the power stroke the connecting rod operates at an angle to the centre line. This causes a side force to be applied by the piston to the cylinder wall. Modern engine design has minimised major thrust by offsetting the centre line and therefore increasing the angle of the connecting rod at TDC, reducing the side force applied to the cylinder wall.



Engine balance
Primary inertia forces

These arise from the force that must be applied to accelerate the piston over the first half of its stroke, and similarly from the force developed by the piston as it decelerates over the second half of its stroke. When the piston is around the mid-stroke position it is then moving at the same speed as the crankpin and no inertia force is being generated. For an engine to be acceptable in practice, the arrangement and number of its cylinders must be so contrived that the primary inertia forces generated in any particular cylinder are directly opposed by those of another cylinder. Where the primary inertia forces cancel one another out in this manner, as for example in an in-line or a horizontally opposed four-cylinder engine with the outer and inner pair of pistons moving in opposite directions, the engine is said to be in primary balance.

Secondary inertia forces



These are due to the angular variations that occur between the connecting rod and the cylinder axis as the piston performs each stroke. As a consequence of this departure from straight-line motion of the connecting rod, the piston is caused to move more rapidly over the outer half of its stroke than it does over the inner half. That is, the piston travel at the two ends of the stroke differs for the same angular movements of the crankshaft. The resulting inequality of piston accelerations and decelerations produces corresponding differences in the inertia forces generated. Where these differing inertia forces can be both matched and opposed in direction between one cylinder and another, as for example in a horizontally opposed four-cylinder engine with corresponding pistons in each bank moving over identical parts of their stroke the engine is said to be in secondary balance. It is not always practicable for the cylinders to be arranged so that secondary balance can be obtained, but fortunately the vibration effects resulting from this type of imbalance are much less severe than those associated with primary imbalance and can usually be minimized by the flexible mounting system of the engine. This is confirmed by the long-established and popular in-line four-cylinder engine, which possesses primary balance but lacks secondary balance. However, the continuing search for greater refinement of running with this type of engine led, in the mid-1970s, to a revival of interest in the use of twin counterbalancing shafts for cancelling out these secondary inertia forces.

In Lanchester's original application of the harmonic balancer, two parallel shafts were fitted below and equidistant from the crankshaft axis. These shafts were geared together to run in opposite directions, with one of them being chain driven at twice the crankshaft speed, and they were provided with bob-weights in or about the plane of symmetry of the engine. The effects of these bob-weights were such that they neutralized each other in respect of their lateral motion, but combined in respect of their vertical motion to give a small harmonic one whose phase was contrary to that created by the error in motion of the pistons. Therefore, when the pistons were at their top and bottom dead centres, the bob-weights were always at their lowest position. In this installation, the geared-together bob-weights are in turn driven from a gear shrunk on to the crankshaft and so positioned that they align with the exact centre of the engine. The balancer gears are matched and timed to each other by suitable markings and also to the crankshaft driving gear. Lubrication for the assembly is provided from the engine main oil gallery.